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COVER

Delta Smelt, *Hypomesus transpacificus*
Photograph by Susan Middleton and David Liittschwager
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BIOLOGICAL CHARACTERISTICS OF MULE DEER IN CALIFORNIA'S SAN JACINTO MOUNTAINS

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Southern mule deer, *Odocoileus hemionus fuliginatus*, were collected from the San Jacinto Mountains of Riverside County in February 1994 and February–March 1995 to describe physical condition, reproductive characteristics, ectoparasites, and prevalence of diseases. Condition of deer in spring differed between years. Reproductive rates during both years were similar to those found in nutritionally stressed deer populations. Breeding periods were earlier than southern mule deer from montane San Diego County. A species of tick, *Dermacentor hunteri*, previously not recorded on deer in California was discovered on deer sharing ranges with bighorn sheep, *Ovis canadensis*.

INTRODUCTION

The California Department of Fish and Game manages southern mule deer, *Odocoileus hemionus fuliginatus*, in the San Jacinto Mountains of Riverside County. Deer in this region are collectively designated the San Jacinto/Santa Rosa (SJ/SR) deer herd and occur at the most northern latitude for this subspecies (Wallmo 1981). Methods to monitor population trends for this deer herd have been difficult to establish and information describing its biological characteristics is limited.

Measures of condition and reproductive performance have been used to assess the productivity and range conditions in many wild cervid populations (Cheatum 1949, Ransom 1965, Baker and Leuth 1967, Brown 1984, Taylor 1996). The usefulness of these parameters to deer managers led Gross (1972) to designate them as "performance indicators." The relative level of condition and reproduction for a deer herd may reflect its relationship to the nutritional carrying capacity of the environment and the intensity of intraspecific competition (Verme 1969, Raedeke and Taber 1985).

Breeding periods for California deer herds vary considerably (Chattin 1948, Taber 1953, Taylor[1] 1991). Reproductive periods of southern mule deer in coastal habitats of San Diego County start earlier and extend longer than any herd previously described in California (Bischoff 1957). In montane San Diego County, southern mule deer parturition was synchronized between years and 80% of births occurred in an 18-day period (Bowyer 1991). Understanding whether reproductive differences exist for

[1] Taylor, T.T. 1991. Ecology and productivity of two interstate deer herds in the eastern Sierra Nevada: East Walker-Mono Lake deer herd study. California Department of Fish and Game, Bishop, California, USA.

southern mule deer in Riverside County may be useful for planning management strategies in the San Jacinto Mountains.

Southern mule deer and peninsular bighorn sheep, *Ovis canadensis cremnobates*, potentially share overlapping ranges in the San Jacinto Mountains. In recent years, the decline of bighorn sheep in these ranges has been well documented (Boyce[2] 1995). Disease transmission between sympatric deer and sheep has not been excluded as a possible sheep mortality factor. In the nearby San Bernardino Mountains, California mule deer, *O. h. californicus*, desert bighorn sheep, *O. c. nelsoni*, and domestic cattle shared rangeland without sharing serious diseases (Singer 1997). A serological examination of deer in the San Jacinto Mountains may increase understanding of disease processes between native ungulates.

To increase knowledge of the SJ/SR deer herd, an investigation of physical condition, reproduction, and serology began in February 1994. The objectives of the study were to 1) quantify body condition indexes for adult female deer, 2) quantify reproductive characteristics for adult female deer and, 3) document the prevalence of disease and ectoparasites in deer.

STUDY AREA

Southern mule deer were collected from the San Jacinto Ranger District of the San Bernardino National Forest and surrounding Bureau of Land Management lands in Riverside County during February 1994 and February–March 1995. A variety of habitat types are found in the 500–3300 m elevation range of the San Jacinto Mountains (Mayer and Laudenslayer 1988). Desert wash and scrub habitats occur at the lowest elevations and paloverde, *Cercidium* spp.; creosotebush, *Larrea tridentata*; and rabbitbrush, *Chrysothamnus* spp., are the dominant species. Mixed chaparral habitats dominate from mid-to upper elevations and are composed generally of ceanothus, *Ceanothus* spp.; chamise, *Adenostoma fasciculatum;* manzanita, *Arctostaphylos* spp.; mountain mahogany, *Cercocarpus ledifolius*; and scrub oak, *Quercus dumosa.* Conifer forest is found at the highest elevations and consists of jeffery, *Pinus jefferi*, and ponderosa, *P. ponderosa*, pine habitats. Precipitation at lower elevations averages 5–20 cm annually, with >60 cm being recorded at higher elevations. A description of the vegetative and topographic diversity for this area is provided by Hickman (1993).

METHODS

Southern mule deer were collected at Rouse Ridge, Fobes Canyon, Baldy Mountain, Black Mountain, and Palm Canyon (Fig. 1). All sampling areas contained similar habitats, with the exception of Palm Canyon. This was the only sample area that contained desert habitats occupied by bighorn sheep. Deer were collected

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[2] Boyce, W.M. 1995. Peninsular bighorn sheep population health and demography study. Final progress report. Contract FG 2247. California Department of Fish and Game, Sacramento, California, USA.

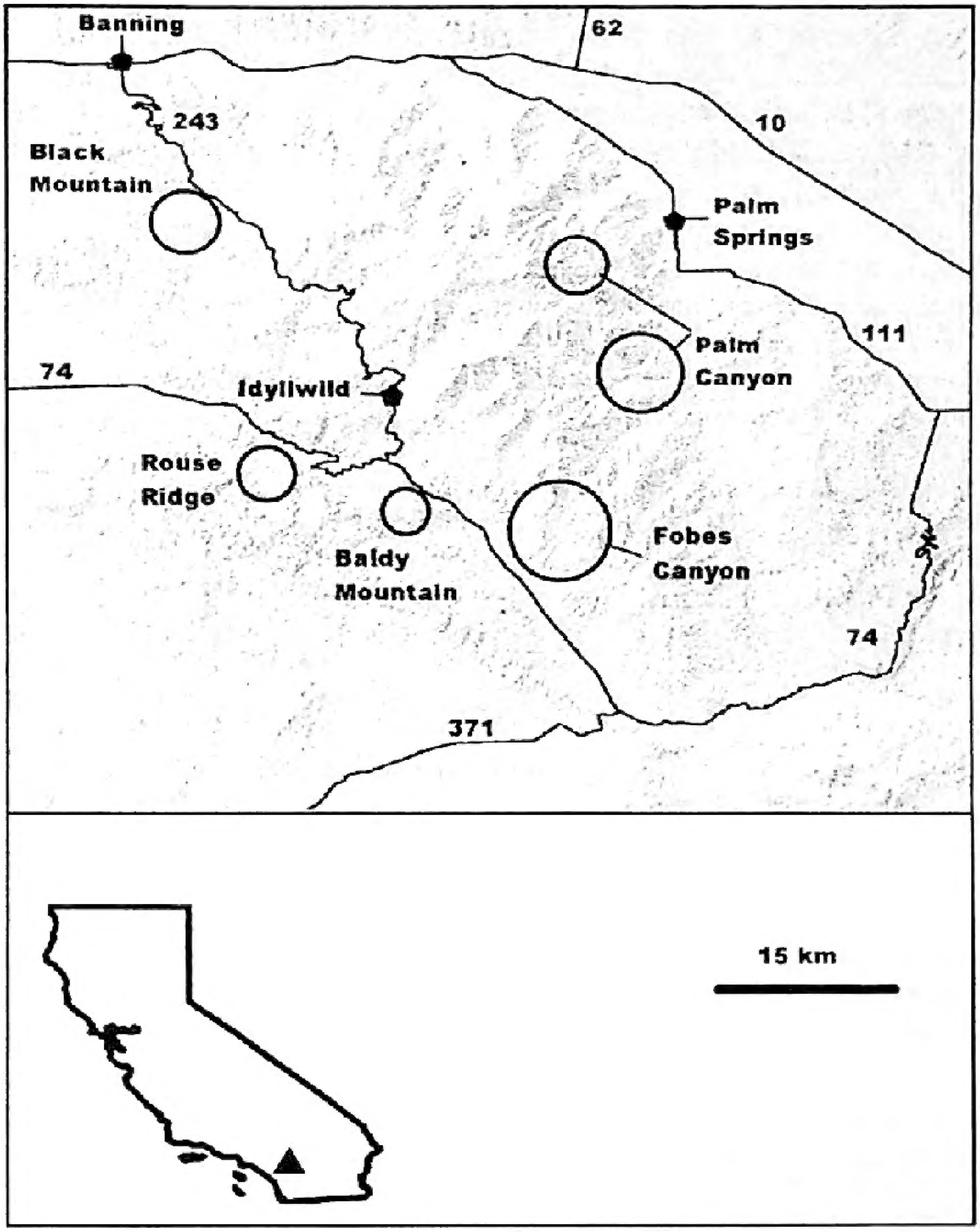

Figure 1. Locations where southern mule deer were collected in the San Jacinto Mountains, Riverside County, California, 1994–1995. Numbers are highway designations.

by teams consisting of a marksman with a rifle and driver, or were collected with a shotgun fired from a helicopter. A total of 20 deer were collected: 8 adult females in 1994, 7 adult females in 1995, and an additional 5 deer of incorrect sex or age that were used only for disease testing.

Immediately after dispatching a deer, a blood sample was taken and stored at 4°C; serum was separated within 12 hours. Both ears were removed from deer and placed into sealed plastic bags for ectoparasite analysis. The deer and all samples were tagged for identification and taken to a central processing station. Fetuses were

removed and aged to the nearest day using a fetal age board (Forestry Suppliers Inc.[3], Jackson, Mississippi, USA). The left kidney, left femur, and left mandible were extracted and frozen until analysis. Kidney, femur, and mandibular fat condition indices were estimated using appropriate techniques (Riney 1955, Ransom 1965, Nichols and Pelton 1974). Two incisors were extracted for age determination using the dental cementum annuli method (Low and Cowan 1963).

Conception and parturition dates were estimated using fetal ages; a gestation period of 204 days was used to calculate these dates (Anderson 1981). Fetal rates were calculated by dividing the number of fetuses by the number of does.

Serum from all southern mule deer was tested for the presence of antibodies to bluetongue virus (BTV), epizootic hemorrhagic disease (EHD), leptospirosis (LEP), brucellosis (BRU), and anaplasmosis (ANA). Additional testing of 1995 sera for ANA used a more sensitive indirect immunofluorescence (IIF) technique (Goff et al. 1990).

I used the G log-likelihood ratio to test for differences between years in disease prevalence. Small sample size required that the nonparametric Mann-Whitney U statistic be used for testing interannual differences in fetal and pregnancy rates, age, and condition indexes. Breeding periods were tested for annual similarity with the U statistic by transforming conception and parturition dates to Julian dates.

RESULTS

Twelve of 15 (80%) female southern mule deer examined were pregnant; pregnancy rate did not differ between years ($U = 31.5$, $P > 0.05$) (Table 1). Two yearling females and 1 mature female (4 years) were not pregnant. Fetal rates were the same in both years at 1.1 fetuses per doe ($U = 29$, $P > 0.05$). Five of 12 (42%) pregnant females were carrying twins, but no triplets were observed. Mean age of female deer differed significantly between years (1994: 2.0, 1995: 4.1) ($U = 54$, $P < 0.01$).

Back-dating from estimated ages of fetuses showed conception occurring from approximately 28 October to 22 November, with a median date of 10 November.

Table 1. Reproductive summary of 15 adult female southern mule deer collected in the San Jacinto Mountains of Riverside County in 1994 and 1995.

Year	Classification	Total number of does	Pregnant does	Total number of fetuses	Mean fetuses per doe (SD)
1994	Does <2 years	3	2	2	0.7 (0.57)
	Does ≥2 years	5	5	7	1.4 (0.54)
	Annual total	8	7	9	1.1 (0.64)
1995	Does <2 years	1	0	0	0
	Does ≥2 years	6	5	8	1.3 (0.81)
	Annual total	7	5	8	1.1 (0.89)

[3] The use of trade names does not imply endorsement by the California Department of Fish and Game.

Estimated parturition ranged from 21 May to 14 June, with a median date of 2 June. Interannual differences in timing of conception (U = 2, P >0.05) and parturition (U = 21.5, P >0.05) were not significant.

Two of the 3 condition indices differed between years (Table 2). The kidney fat index varied significantly between years (U = 51, P <0.01), with a mean of 61.3% (range = 21–115%) in 1994 and 20.0% (range = 11–33%) in 1995. Femur marrow fat varied significantly between years (U = 54, P <0.01) with a mean of 76.3% (range = 65–85%) in 1994 and 52.1% (range = 22–71%) in 1995. Mandibular marrow fat did not differ between years (U = 19, P >0.05) with a mean of 59.0% (range = 53–64%) in 1994 and 54.7% (range = 22–69%) in 1995.

Positive titers to BTV, EHD, and ANA were detected in 1994 and 1995; testing for BRU and LEP was negative for both years (Table 3). Interannual prevalence of antibodies to BTV, EHD, and ANA did not differ significantly (G = 1.27, df = 2, P >0.10). For the years combined, exposure rates were 35% for BTV, 50% for EHD, and 45% for ANA.

Sera from 1995 tested for ANA using the IIF method showed a greater number of positive results than standard testing. These results were positive for 70% (n = 10) of all samples; titers ranged from 1:100 to 1:3500 (Table 4).

Three genera of parasites representing 2 classes and 3 orders were identified from the ears of southern mule deer (Table 5). Sucking lice, *Linognathus ovillus*, and

Table 2. Kidney fat (KFI), femur marrow fat (FMF), and mandibular marrow fat (MMF) condition indexes for 15 adult female southern mule deer collected in the San Jacinto Mountains of Riverside County in February 1994 and February–March 1995.

	KFI%		FMF%		MMF%	
Year	Mean	SD	Mean	SD	Mean	SD
1994	61.3	34.40	76.3	7.67	59.0	3.46
1995	20.0	8.89	52.1	18.45	54.7	11.89
Total	42.6	32.47	65.1	18.20	56.0	8.70

Table 3. Positive titers by sample area to bluetongue virus (BTV), epizootic hemorrhagic disease (EHD), brucellosis (BRU), anaplasmosis (ANA), and leptospirosis (LEP) for southern mule deer collected from the San Jacinto Mountains of Riverside County in February 1994 and February–March 1995.

Year	Area	Deer Sampled	BTV	EHD	BRU	LEP	ANA
1994							
	Rouse Ridge	2	0	0	0	0	0
	Fobes Canyon	5	2	4	0	0	3
	Baldy Mountain	2	0	1	0	0	1
	Black Mountain	1	0	0	0	0	1
1995							
	Palm Canyon	4	1	2	0	0	2
	Fobes Canyon	4	3	2	0	0	1
	Baldy Mountain	2	1	1	0	0	1
Total Sample		20	7	10	0	0	9
Total % exposure			35%	50%	0%	0%	45%

Table 4. Deer collection locations and antibody titers against anaplasmosis using an indirect immunofluorescence test for 10 southern mule deer collected in the San Jacinto Mountains of California in February–March 1995.

Palm Canyon	Fobes Canyon	Baldy Mountain
1:100	0	1:800
1:3200	1:200	0
1:200	1:200	
1:800	0	

Table 5. Occurrence by sample area of hard tick, *Dermacentor* spp.; sucking louse, *Linognathus ovillus*; and deer ked, *Neolipoptena ferrisi*, on southern mule deer collected in the San Jacinto Mountains of Riverside County in February 1994 and February–March 1995.

Year	Area	Total number of deer	*D. occidentalis*	*D. albipictus*	*D. hunteri*	*L. ovillus*	*N. ferrisi*
1994	Rouse Ridge	2	1	0	0	0	1
	Fobes Canyon	5	4	1	0	0	1
	Baldy Mountain	2	0	0	0	0	0
	Black Mountain	1	1	0	0	0	0
1995	Palm Canyon	4	2	0	2	0	0
	Fobes Canyon	4	2	0	0	1	0
	Baldy Mountain	2	2	0	0	1	0
Total		20	12	1	2	2	2

louse flies, *Neolipoptena ferrisi*, were identified in 10% of all samples (n = 20). Three species of ticks from the genus *Dermacentor* (*D. occidentalis*, *D. albipictus*, and *D. hunteri*) were identified in 70% of all samples. The presence of *D. hunteri* on 2 deer in Palm Canyon is the 1st recorded observation of this species on mule deer in California (Crosbie et al. 1997).

DISCUSSION

The order of utilization and replacement of depot fat varies between storage sites, making no single site a good index for the entire range of possible body conditions (Connolly 1981). Serum lipids are mobilized first, followed by subcutaneous fat; visceral fat; and, ultimately, marrow fat. Fat reserves of lower mobility are often more desirable as measures of condition because they represent longer-term nutritional intake, are less susceptible to short-term fluctuations, and are last to be depleted under severe stress (Kie[4] 1988). The condition indexes used in this study were from low mobility reserves and are most useful as indicators of poor condition during periods of nutritional duress.

[4] Kie, J.G. 1988. Performance in wild ungulates: Measuring population density and condition of individuals. General Technical Report PSW-106. USDA Forest Service, Pacific Southwest Forest and Range Experiment Station, Berkeley, California, USA.

Deer in southern California are primarily resident and depend on phenology and protein quality of forage on permanent deer ranges to regulate physical condition. Deer in this region generally reach minimum levels of condition by early autumn, after long dry periods reduce forage values and produce prolonged periods of poor-quality diet (Longhurst et al. 1952, Bowyer 1987). Autumn precipitation begins a period of increased forage quality, nutritional recovery, and improving physical condition. Condition indexes measured in this study were for deer collected during peak foraging conditions and depot fat replacement, and were relatively high compared to deer measured during times of nutritional stress and depot fat mobility (Kie et al. 1983, Taylor 1996). These indices provided little information on the overall condition of deer, but showed reduced annual replacement of depot fat in spring 1995. This interannual difference in spring condition may be due to the timing of rejuvenated vegetation prior to collections or the small sample size used in this study because of low deer densities and difficulty collecting deer.

Fetal rates for combined years were lower than found by Bischoff (1958) in coastal San Diego County and similar to high-density, nutritionally stressed white-tailed deer, *Odocoileus virginianus*, and Rocky Mountain mule deer, *O. h. hemionus*, populations (Kie et al. 1983, Kucera[5] 1988). Bowyer (1991) observed that twinning was rare in montane San Diego County and estimated that the fawn:adult female ratio at parturition was 0.5:1. Fetal rates are valuable indicators of condition because they are sensitive to changes in nutritional intake and habitat (Kie[4] 1988). Maternal age can also affect fetal rates, as female deer <2 years produce fewer fetuses than older deer (Anderson 1981). Fetal rates did not differ between years in this study, even though the condition of deer in spring decreased significantly. This may be due to the inadequacy of depot fat indexes for determining overall condition during periods of depot fat replacement, or an increase in the age and, therefore, productivity of deer sampled in 1995.

Timing of reproductive periods in deer has been related to differences in photoperiod and plant phenology associated with latitude and altitude (Robinette et al.[6] 1977, Nicholson[7] 1995). Successful reproductive strategy in mammals generally requires coordination of lactation demands with timing of herbaceous green-up (Vaughan 1986). Contrary to this, deer in montane San Diego County synchronized parturition with dry climatic conditions and low forage quality (Bowyer 1991). Deer in my study were sampled at similar altitudes, but more northern latitudes than in San Diego County and had similar durations and annual synchronization of reproductive periods. However, peak periods of conception and parturition were 25 days earlier in the San Jacinto Mountains. This difference in reproductive timing

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[5] Kucera, T.E. 1988. Ecology and population dynamics of mule deer in the eastern Sierra Nevada, California. Ph.D. Dissertation, University of California, Berkeley, California, USA.

[6] Robinette, W.L., N.V. Hancock, and D.A. Jones. 1977. The Oak Creek mule deer herd in Utah. Utah State Division of Wildlife Resources, Publication 77-15.

[7] Nicholson, M.C. 1995. Habitat selection by mule deer: Effects of migration and population density. Ph.D. Dissertation, University of Alaska, Fairbanks, Alaska, USA.

may be due to the influence of interannual variation in precipitation and changing weather patterns related to >20 years between data sets. Another possibility may be variations in methods used for determining parturition, as Bowyer (1991) used field observations of newborn fawns for estimating reproductive dates.

The unique observation of *D. hunteri* on southern mule deer is notable, as a recent study in southern California showed that exposure to ANA in desert bighorn sheep was limited to those infested with *D. hunteri* (Crosbie et al. 1997). The high titers indicated by the IIF method may suggest active infection, but cannot be confirmed without identification of the parasite from stained blood smears. A serological survey of California deer herds showed a seropositivity of 34% (n = 792) in deer tested for antibodies against ANA (Behymer et al. 1989). More recently, in San Diego County, 33% (n = 18) of southern mule deer tested positive for antibodies against ANA (CDFG[7] 1994). Whether ANA or *D. hunteri* play a role in the health of native ungulates in this region remains unclear.

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EFFECTS OF STOCKING DENSITY ON GROWTH, GROSS COMPOSITION, AND PLASMA AND HEPATIC METABOLITE LEVELS IN PALMETTO BASS, *MORONE SAXATILIS* x *M. CHRYSOPS*

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Juveniles of palmetto bass, *Morone saxatilis* x *M. chrysops*, were stocked at low (0.7 kg/m^3), medium (1.4 kg/m^3) and high (2.8 kg/m^3) densities. Fish were held in 2.4-m^3 tanks and fed to satiation twice daily with floating pelleted feed for an 84-day rearing period. The highest percent weight gain and specific growth rate were obtained in fish raised at medium stocking density; significant differences were found only between low and medium stocking densities. Both the food intake and specific growth rate declined during the course of the experiment. The relationship between proximate composition and growth of fish is less apparent; however, fish with good growth (at medium stocking density) contained more lipid, whereas those with poor growth (at low density) had lower lipid content. The correlation between growth rate and stocking density may be dependent on social interactions, physical constraints, and threshold level of stocking density. The preliminary results of the relationship between plasma and hepatic metabolite levels and stocking densities are also shown.

INTRODUCTION

Stocking density is generally considered an important factor in determining production costs and related capital investment of aquaculture. Further, high stocking density is commonly used to maximize water use and increase production in intensive aquaculture. However, some investigations have shown that the growth rate of fish is negatively related to stocking density (Refstie 1977, Trzebiatowski et al. 1981, Papoutsoglou et al. 1987, Holm et al. 1990). Consequently, high stocking density is regarded as an environmental stressor (Wedemeyer 1976, Fagerlund et al. 1981, Klinger et al. 1983, Gatlin et al. 1986). The growth-altering effect of increased stocking density has been attributed to reduced food consumption (Fenderson and Carpenter 1971), social interaction (McIntyre et al. 1979, Scott and Currie 1980), deteriorated water quality (Smart 1981, Pickering and Pottinger 1987), crowding stress (Fenderson and Carpenter 1971, Pickering and Pottinger 1989), and physiological changes (Nokes and Leatherland 1977, Ejike and Scherck 1980). In contrast, the growth of Arctic char, *Salvelinus alpinus*, increases at high stocking density (Jobling 1985, Wallace et al. 1988, Christiansen and Jobling 1990, Jorgensen et al. 1993). The reasons for such disparate results are not understood.

Palmetto bass (cross between female striped bass, *Morone saxatilis*, and male white bass, *M. chrysops*) have received considerable attention in Taiwan for culture as food fish and, perhaps, for use in fee-fishing ponds. They are attractive for aquaculture because of their temperature and salinity tolerance, rapid growth, consumer appeal, and high market value (Harrell et al. 1988, Tucker et al. 1993). Except for some descriptions of culture techniques (Kerby et al. 1983, Woods et al. 1985, Kerby et al. 1987), little is known about the effect of stocking density on the growth of palmetto bass. Therefore, our study attempts to elucidate the effect of stocking density on growth performance as defined by food consumption, growth rate, and body composition. In addition, liver and plasma metabolite levels were also measured to evaluate the relationship between stocking density and physiological changes.

METHODS

Palmetto bass juveniles were obtained from a private fish farm in southern Taiwan during autumn 1996. Fish were maintained in an outdoor concrete pond (8.0 x 7.9 x 0.8 m) until required for the trial. The pond was fully aerated and supplied with an 80-liters/minute flow of well water. Fish were fed a commercial floating pellet.

Prior to the experiment, fish were transported from the holding pond to 6 indoor recirculating freshwater tanks (2.0 × 1.7 × 0.7 m). The fish were randomly distributed into each tank at a fairly evenly sized mean weight of 30.34 g (SD = 5.88). They were divided into 2 replicate groups of 40, 80, and 160 fish, equivalent to low, medium and high density groups of 0.7, 1.4, and 2.8 kg/m^3. The tanks were maintained under a 12 hours light:12 hours dark photoperiod and supplied with filtered, aerated, and thermostatically controlled well water at a flow rate of 96 liters/minute. The experimental temperature (26±0.5°C) was reached within 3 days. This temperature was selected to optimize growth and feed efficiency for palmetto bass (Woiwode and Adelman 1991). Fish were acclimated for 2 weeks, after which they were weighed and measured again before the start of the experiment.

The fish were fed to satiation twice daily with floating pelleted feed (Fwusow Industry Co.[4], Taiwan, R.O.C.; 0.45-cm diameter), containing 51.05% protein, 8.03% fat, 11.45% ash, and 8.93% moisture. Moisture, crude protein, crude fat, and ash levels in feed were measured using Association of Official Analytical Chemists methods (AOAC 1990). Fish were considered satiated when several feed pellets remained on the water surface for more than 10 minutes. Uneaten feed was removed, weighed, and the dry weight estimated from wet weight using a conversion factor for water absorption of 3.13.

Dissolved oxygen (DO) and total ammonia nitrogen (TAN) concentrations were recorded on day 56 and day 84. Two 125-ml samples of tank water were collected and pooled together and then 3 subsamples were analyzed for TAN concentrations using the automated phenate method (APHA et al. 1995). Dissolved oxygen was

[4] Use of trade names does not imply endorsement by the California Department of Fish and Game.

measured with a recording oxygen temperature meter (Model 56, YSI, Inc.[4], Yellow Springs, Ohio, USA) at the time of sampling for ammonia. Oxygen consumption rates were calculated by stopping tank inflow for 1 hour and measuring the resulting decrease in dissolved oxygen levels. Measurements were conducted at a fixed time (between 0900 and 1000 hours) to minimize possible variation in oxygen consumption.

The experimental period was 84 days. Once every 3 weeks, samples of 30 fish were weighed and measured individually to the nearest 0.1 g and 0.1 cm. At the start and the end of the experiment, 3 fish from each tank were sacrificed for proximate analysis. At the end of the experiment, fish were individually weighed and measured. Wet weights of liver and visceral fat were measured for 6 fish at that time.

Physiological data were collected for 6–12 fish from each experimental group. Blood from caudal severance was collected in heparinized tubes and centrifuged; plasma was stored at –60°C until it was assayed. Hematocrit was measured using standard heparinized hematocrit tubes. Pieces of liver were frozen for glycogen measurement (Lo et al. 1970). Plasma glucose and protein levels were determined using Sigma assays (Sigma Chemical Co.[4], St. Louis, Missouri, USA). Plasma lipid class composition was analyzed with Iatroscan MK-S TLC/FID chromatographic analyzer (Iatron Laboratories, Inc.[4], Tokyo, Japan) following the method of Iatron Laboratories[5] (1987).

Growth performance was calculated with the following equations:

percent weight gain (%) = $[(W_2 - W_1) \times 100]/W_1$,

daily growth rate (%) = $[(W_2 - W_1) \times 100]/[t\,(W_2 + W_1)/2]$,

specific growth rate (%) = $[(\ln W_2 - \ln W_1) \times 100]/t$,

daily food intake (%) = $(F \times 100)/[t\,(W_2 + W_1)/2]$, and

feed conversion efficiency (%) = $[(W_2 - W_1) \times 100]/F$,

where W_1 = initial mean body weight of fish (g),
W_2 = final mean body weight of fish (g),
t = experiment duration in days, and
F = amount of feed consumed (g).

Data were analyzed using 1-way analysis of variance (ANOVA). Comparisons between treatment means were made with Duncan's multiple range test. Statistical results were considered significant if $P < 0.05$.

RESULTS

The effect of stocking density varied for different measures of growth performance. Mean individual weight at harvest in fish stocked at low density was smaller, but not significantly ($P > 0.05$), than those at medium and high densities (Table 1). Weight gain for fish held at medium and high stocking densities was significantly higher than for those at low density ($P < 0.05$) (Table 1). Percent weight gain followed a pattern similar to weight gain except that a significant difference was observed only between the fish stocked at medium and low densities ($P < 0.05$). Differences in both

[5] Iatron Laboratories. 1987. Analysis of serum lipids by the Iatroscan. *In*: Iatroscan Instrument Application, No. 14. Iatron Laboratories, Inc., Tokyo, Japan.

daily growth rate and specific growth rate between medium and low densities were significant ($P < 0.05$), whereas the differences between medium and high densities, as well as between low and high densities, were not ($P > 0.05$). Food intake did not vary significantly with stocking density ($P > 0.05$) and no significant differences were observed between treatments with respect to feed conversion efficiency ($P > 0.05$).

As expected, initial specific growth rate was high for all the density groups, then declined over time as fish grew (Table 2). Consistent with the significantly greater mean specific growth rate of fish at medium density, for each 3-week period of the experiment specific growth rate was highest at medium density. Similarly, at each density, daily food intake decreased significantly ($P < 0.05$) during the course of the experiment (Table 3).

Table 1. Growth performance of the juvenile palmetto bass stocked at different densities and fed ad libitum for 84 days. Values are means ±1 SD from duplicate groups of fish with 30 fish/group. Means with different superscripts in the same row are significantly different ($P < 0.05$).

	Stocking density (fish/tank)		
Variable	40	80	160
Initial individual weight (g)	30.19±6.06	29.97±5.81	30.87±5.83
Final individual weight (g)	138.55±30.89	149.91±29.03	147.99±31.90
Weight gain (g)	108.36±0.09[b]	119.94±0.52[a]	117.12±3.01[a]
Percent weight gain (%)	358.99±1.07[b]	400.36±5.28[a]	379.47±10.49[ab]
Daily growth rate (%)	1.98±0.01[b]	2.05±0.01[a]	2.02±0.02[ab]
Specific growth rate (%)	2.35±0.01[b]	2.48±0.05[a]	2.41±0.03[ab]
Survival rate (%)	100	100	99.69
Feed intake (%)	2.53±0.01	2.60±0.04	2.63±0.01
Feed conversion effeciency (%)	78.13±0.15	79.14±0.80	76.73±0.76

Table 2. Periodic mean specific growth rates (%/day) of palmetto bass stocked at 3 different densities.

Period	Stocking density (fish/tank)		
(days)	40	80	160
1–21	4.75	5.06	4.97
22–42	2.40	2.51	2.45
43–63	1.44	1.52	1.44
64–84	1.08	1.16	1.09

Table 3. Periodic mean daily food intakes (g/g fish/day) of palmetto bass stocked at 3 different densities.

Period	Stocking density (fish/tank)		
(days)	40	80	160
1–21	4.44	4.40	4.40
22–42	2.87	2.96	3.00
43–63	2.16	2.22	2.26
64–84	1.65	1.81	1.76

On day 56 of the experiment, DO was 6.3, 4.9, and 3.9 mg/liter at low, medium, and high stocking densities while TAN was 0.05, 0.09 and 0.20 mg/liter (Table 4). Due to low DO at higher densities, back washing was conducted on day 57 in order to maintain water quality at safe levels. Thus, on day 84, when water quality was measured again, DO was higher and TAN was lower than on day 56 (Table 4). Rates of oxygen consumption declined with increasing stocking densities on both measuring days.

Size composition at harvest varied among the 3 stocking densities of palmetto bass (Fig. 1). The percentage of large fish (>160 g) at medium density (35.4%) was significantly (P <0.05) higher than at low density (27.5%), whereas the percentage of small fish (<120 g) in fish stocked at low density (26.3%) was significantly (P <0.05) higher than at medium density (16.1%).

Proximate analysis revealed variable effects of stocking density on different body components. Moisture and ash content of palmetto bass were not significantly

Table 4. Mean dissolved oxygen (between 0900 and 1000 hours), oxygen consumption rate, and total ammonia nitrogen in tanks used to culture palmetto bass at low (40 fish/tank), medium (80 fish/tank), and high (160 fish/tank) stocking densities.

	Day 56			Day 84		
Variable	Low	Medium	High	Low	Medium	High
Dissolved oxygen (mg/liter)	6.3	4.9	3.9	6.2	5.5	4.5
Oxygen consumption [mg/(kg fish/hour)]	224.3	156.1	132.1	178.5	131.7	118.5
Total ammonia nitrogen (mg/liter)	0.05	0.09	0.20	0.01	0.02	0.04

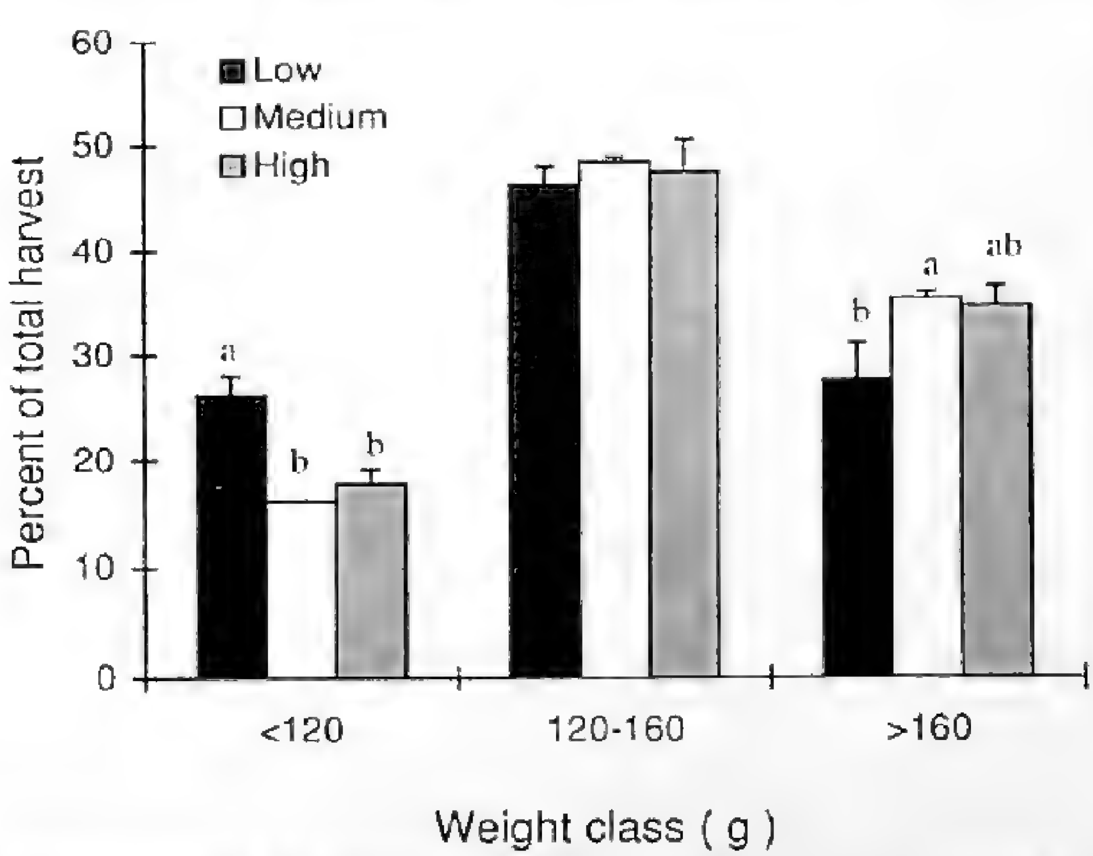

Figure 1. Frequency of 3 weight classes at harvest of palmetto bass stocked at low, medium and high densities. Data represent mean ±1 SD. Columns with different letter are significantly different (P <0.05).

(P >0.05) different among densities (Table 5). Lipid content in fish reared at medium density was significantly higher than at low density (P <0.05). Protein content was significantly higher in fish reared at medium and high density than at low density (P <0.05). Condition factor did not vary significantly among densities.

Physiological variables exhibited different responses to stocking density (Table 6). Hematocrit was significantly lower at high density (P <0.05). Hepatosomatic index and hepatic glycogen values increased with increasing stocking densities, but no significant differences between rearing groups were observed. Plasma glucose and triglyceride levels were significantly higher in fish stocked at high density than at low density (P <0.05). Plasma protein level did not differ significantly among treatments. Plasma free fatty acid levels were lowest in fish raised at low stocking density, but differences were not significant.

DISCUSSION

Previous studies have shown an inverse correlation between growth rate and stocking density in fish culture (Soderberg and Krise 1986, Vijayan and Leatherland

Table 5. Muscle proximate composition and condition factor of palmetto bass reared at 3 different densities. Values are means ±1 SD; sample size in parentheses. Means in each row with the same superscripts are not significantly different (P <0.05).

		Stocking density (fish/tank)		
Variable	Initial	40	80	160
Moisture (%)	76.48±0.33(6)	74.71±0.32(6)	74.42±0.18(6)	74.68±0.34(6)
Crude protein (%)	20.22±0.33(6)	20.22±0.05^{b}(6)	20.50±0.08^{a}(6)	20.48±0.11^{a}(6)
Lipid (%)	1.60±0.13(6)	2.78±0.19^{b}(6)	3.37±0.15^{a}(6)	3.05±0.18^{ab}(6)
Ash (%)	1.37±0.02(6)	1.43±0.01(6)	1.42±0.01(6)	1.41±0.01(6)
Condition factor[c]		1.32±0.10(80)	1.37±0.09(160)	1.35±0.09(319)

[c] Condition factor = (body weight × 100)/(total length)^3

Table 6. Effect of stocking density on hematocrit, hepatosomatic index (HSI), liver glycogen, plasma glucose, protein, triglyceride, and free fatty acid in juvenile palmetto bass reared at 3 different densities. Values are means ±1 SD; sample size in parentheses. Means in the same row with different superscripts are significantly different (P <0.05).

	Stocking density (fish/tank)		
Variable	40	80	160
Haematocrit (%)	33.81±0.55^{a}(24)	35.15±0.95^{a}(24)	31.44±0.81^{b}(24)
HSI[c] (%)	1.75±0.12(12)	1.76±0.05(12)	1.80±0.12(12)
Glycogen (mg/g)	13.83±0.25(6)	14.54±0.49(6)	15.16±1.12(6)
Glucose (mg/dl)	155.87±5.71^{b}(12)	167.33±8.28^{ab}(12)	184.89±10.10^{a}(12)
Protein (g/dl)	3.47±0.18(12)	3.58±0.21(12)	3.60±0.16(12)
Triglyceride (mg/dl)	315.52±21.49^{b}(12)	345.09±17.67^{ab}(12)	385.46±20.42^{a}(12)
Free fatty acid (mg/dl)	31.86±3.77(12)	35.38±2.12(12)	34.59±2.94(12)

[c] HSI = (wet weight of liver × 100)/(body weight)

1988, Zonneveld and Fadholi 1991, Bjornsson 1994). However, weight gain and growth rate of palmetto bass in our study were greatest at higher stocking densities. The difference between our results and others may be due to differences in experimental conditions, fish size and age (Jorgensen et al. 1993), or possibly fish species and stocking levels.

In aquatic animals with social hierarchies, social interaction may elicit aggressive behavior as a result of territorial defense and competition for food (Keenleyside and Yamamoto 1962, Fenderson and Carpenter 1971). Low-ranking fish may display a distinct stress response (Yamagishi et al. 1974, Nokes and Leatherland 1977, Ejike and Schreck 1980, Scott and Currie 1980) that leads to reduced food intake and results in a growth suppression. Therefore, a hypothesis that may explain the results obtained here is that high stocking density inhibits the development of agonistic behavior due to the breakdown of dominance hierarchies while simultaneously stimulating the establishment of schooling behavior, which is considered to have a positive effect on feeding (Frost 1977). On the other hand, fish raised at low densities may develop defense territories or dominance hierarchies, resulting in stress and reduced growth.

The higher rate of oxygen consumption at low density in our study is consistent with the hypothesis that aggressive behavior is more prominent at low density. High levels of social interaction associated with aggressive behavior elevates metabolic rate and may increase oxygen consumption (Christiansen et al. 1991).

The decrease in the specific growth rate during the experiment (Table 2) followed the typical pattern of fish growth: growth rate decreases as size increases. Moreover, the decrease in food intake by fish as they grew is consistent with the pattern in specific growth rate.

It is likely that our highest density was not high enough to elicit a general crowding-stress response associated with high stocking density that would adversely affect growth (Vijayan and Leatherland 1988). In our study, more fish >160 g were harvested at the medium and high stocking densities than at low density, whereas more fish <120 g were observed at low density. This suggests that the negative effect of stocking density only becomes evident as a certain threshold level is approached. This concurs with Kawanabe (1969), who demonstrated that the growth rate of ayu, *Plecoglossus altivelis*, increased with a moderate increase in density until the point at which a stress response occurs.

Elevated ammonia levels and inadequate DO impair the growth of fish stocked at high density (Wallace et al. 1988). Although water quality was not monitored frequently during our experiment, the 2 measurements that were taken suggest that ammonia levels were higher and DO was lower at high stocking density than at low stocking density. However, these levels were apparently not high enough to depress growth.

In general, fish that grow well contain more lipid and less moisture than those that grow poorly. However, protein and ash are not affected by growth rate (Fagerlund et al. 1981, Hung et al. 1993). The relationship between proximate composition and growth of fish in our study was consistent with those generalities, except for protein content, which was greater at higher densities.

Based on other studies (Kerby et al. 1987, Jorgensen et al. 1993), we expected condition factor to be higher in the fastest growing fish. However, we found no significant difference in condition of fish stocked at different densities.

The lower glucose level of fish held at low stocking density probably reflected their lower food intake (Vijayan and Leatherland 1988, Vijayan et al. 1990). Triglycerides are an important energy source in fish and appear to be mobilized to cope with the increased energy demand. Therefore, certain hematological parameters, such as glucose and triglycerides, are low at lower stocking density, perhaps reflecting lower average food intake and/or higher metabolic rate. However, the correlation between stocking density and other nutrient reserves such as plasma protein and free fatty acid was not found to be significant. Consequently, further studies are necessary before the relevant mechanism can be completely understood.

In conclusion, the current study has demonstrated that stocking density affects the growth and gross composition of palmetto bass. However, the relationship between growth rate and stocking density is dependent on behavioral (social interaction) and physical (water quality) factors, as well as any threshold response at high stocking density. Further studies are required to adequately determine the relationship between plasma and hepatic metabolite levels and stocking density.

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RESOURCE STATUS REPORTS

INTRODUCTION

In this issue we begin a new section that will contain informational reports describing abundance trends and status of California's living resources. These articles will summarize the knowledge of Department of Fish and Game experts on important species or group of species. California is the 3rd largest state and perhaps the most varied in its habitats and biological resources. At present there is no way to easily access up-to-date information on many of the state's important species. Such information is needed by conservation organizations, the Legislature, the media, educational institutions, the general public, and the Department itself.

We will publish as many status reports as space and the need to publish peer-reviewed papers allow. Thus, it will take several years to produce status reports on all important resources. Fortunately, for most resources annual updates will be unnecessary; status reports on most species need only appear every few years.

By publishing status and trends reports, *California Fish and Game* departs from its recent role as a strictly scientific publication. However, the true role of the journal is to foster conservation through education, as stated in the motto on the cover. The Resource Status Reports section attempts to do exactly that.

The first installment of the new section contains status reports on delta smelt, splittail, striped bass, and white sturgeon. These are species found in the Sacramento-San Joaquin Estuary, which has been under great stress from a variety of human activities. The delta smelt and splittail are non-game fishes listed as threatened, the striped bass is an introduced sport fish, and the white sturgeon is a native sport fish.

—*James J. Orsi*
—*David W. Kohlhorst*
Co-Editors-in-Chief

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STATUS OF DELTA SMELT IN THE SACRAMENTO-SAN JOAQUIN ESTUARY

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The delta smelt, *Hypomesus transpacificus*, is a small euryhaline fish that reaches adult sizes of 60–80 mm fork length (Stevens et al.[1] 1990) and historically was one of the most common fishes in the Sacramento-San Joaquin Estuary (Erkkila et al. 1950, Radtke 1966). It is translucent with a silvery, steel-blue streak along its sides. The delta smelt resides primarily in and near the low salinity zone (Ganssle 1966, Stevens et al.[1] 1990, Moyle et al. 1992). It is considered environmentally sensitive because it is endemic to the estuary (Moyle 1976, Stevens et al.[1] 1990, Moyle et al. 1992), is primarily an annual fish (Moyle 1976, Sweetnam and Stevens[2] 1993), is exclusively planktivorous and dependent on a zooplankton community which has been greatly altered by exotic species (Moyle 1976; Nobriga and Lott[3], in preparation; Lott and Nobriga[4], in preparation), has low fecundity for a fish with planktonic larvae (Moyle et al. 1992, USFWS[5] 1995a, Mager[6] 1996), is easily stressed (Swanson and Cech[7] 1995, Swanson et al. 1996), and is a poor swimmer (Swanson et al. 1998). Unlike many fishes with similar life histories in the estuary, delta smelt abundance is not strongly affected by freshwater outflow (Stevens and Miller 1983) or by the position of the 2‰ isohaline (Jassby et al. 1995); however, population levels are high only in years with moderate to high outflow (USFWS 1995a). Delta smelt do not exhibit

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[6] Mager, R.C. 1996. Gametogenesis, reproduction, and artificial propogation of delta smelt, *Hypomesus transpacificus*. Ph.D. Dissertation, University of California, Davis, California, USA.

[7] Swanson C. and J.J. Cech. 1995. Environmental tolerances and requirements of the delta smelt, *Hypomesus transpacificus*. Final report to the California Department of Water Resources, Contracts B-59449 and B-58959, Sacramento, California, USA.

a strong stock-recruitment relationship as would be expected for a near-annual fish (Stevens et al.[1] 1990, Sweetnam and Stevens[2] 1993). Thus, environmental conditions may strongly contribute to population success (Moyle et al. 1992, Sweetnam and Stevens[2] 1993).

A non-native congener from Japan, the wakasagi, *Hypomesus nipponensis*, recently became a permanent resident of the estuary (Aasen et al. 1998) and now competes and hybridizes with delta smelt (Stanely et al. 1995, Trenham et al. 1998). The wakasagi entered the estuary after being introduced as a forage fish for salmonids in upstream reservoirs in 1959, when both the delta smelt and wakasagi were considered to be *H. olidus* (Wales 1962).

The delta smelt was listed as "threatened" under the Federal Endangered Species Act on 5 March 1993 (USFWS[8] 1993) and was also listed as "threatened" pursuant to the California Endangered Species Act on 9 December 1993. Diversion of freshwater outflow by the State and Federal Water Projects has been changed to protect delta smelt (USFWS[9] 1995b) and new water quality standards were enacted by the State in 1995 to provide better habitat conditions in the spring, in part for delta smelt (SWRCB[10] 1995; for a history of water development impacts, see Arthur et al. 1996).

Information from 5 trawl surveys, a beach seine survey, and fish salvage at State Water Project and Federal Central Valley Project fish screens documented temporal trends that resulted in the listing of the species (USFWS[8] 1993). Four of these data sets are presented here (Fig. 1). Historically, delta smelt abundance fluctuated annually, but from the late 1970s or early 1980s to 1992, abundance was consistently low (Sweetnam and Stevens[2] 1993). Since 1992, abundance has varied dramatically between years and surveys (Fig. 1). Most recently, the 1998 summer townet abundance index was 3.3, which is relatively low (Fig. 1a). The fall midwater trawl index was only moderately low, at 417.6, in 1998 (Fig. 1b). Chipps Island trawl catches were low in 1998 and have been consistently low since 1984, except for 1996 (Fig. 1c). Salvage at the State Water Project (Fig. 1d) and Central Valley Project has remained low due to take restrictions in place since 1993 (USFWS9 1995b) and may no longer track abundance trends.

Since the early 1990s, mean fork length of adult delta smelt captured by the fall midwater trawl survey has declined significantly ($t = 55.9$; $df = 5,100$; $P < 0.001$), from 63.0 mm in 1975–1991 to 53.9 mm in 1992–1997 (Fig. 2). Potential causes of this apparent change in growth rate are being investigated.

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[8] USFWS. 1993. Final rule listing the delta smelt as a threatened species. Federal Register, 5 March 1993 (58 FR 12854).

[9] USFWS. 1995b. Formal consultation and conference on effects of long-term operation of the Central Valley Project and the State Water Project on the threatened delta smelt, delta smelt critical habitat, and proposed threatened Sacramento splittail. U.S. Fish and Wildlife Service, Portland Oregon, USA.

[10] SWRCB (State Water Resources Control Board). 1995. Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Estuary, 95-1WR, May 1995. Sacramento, California, USA.

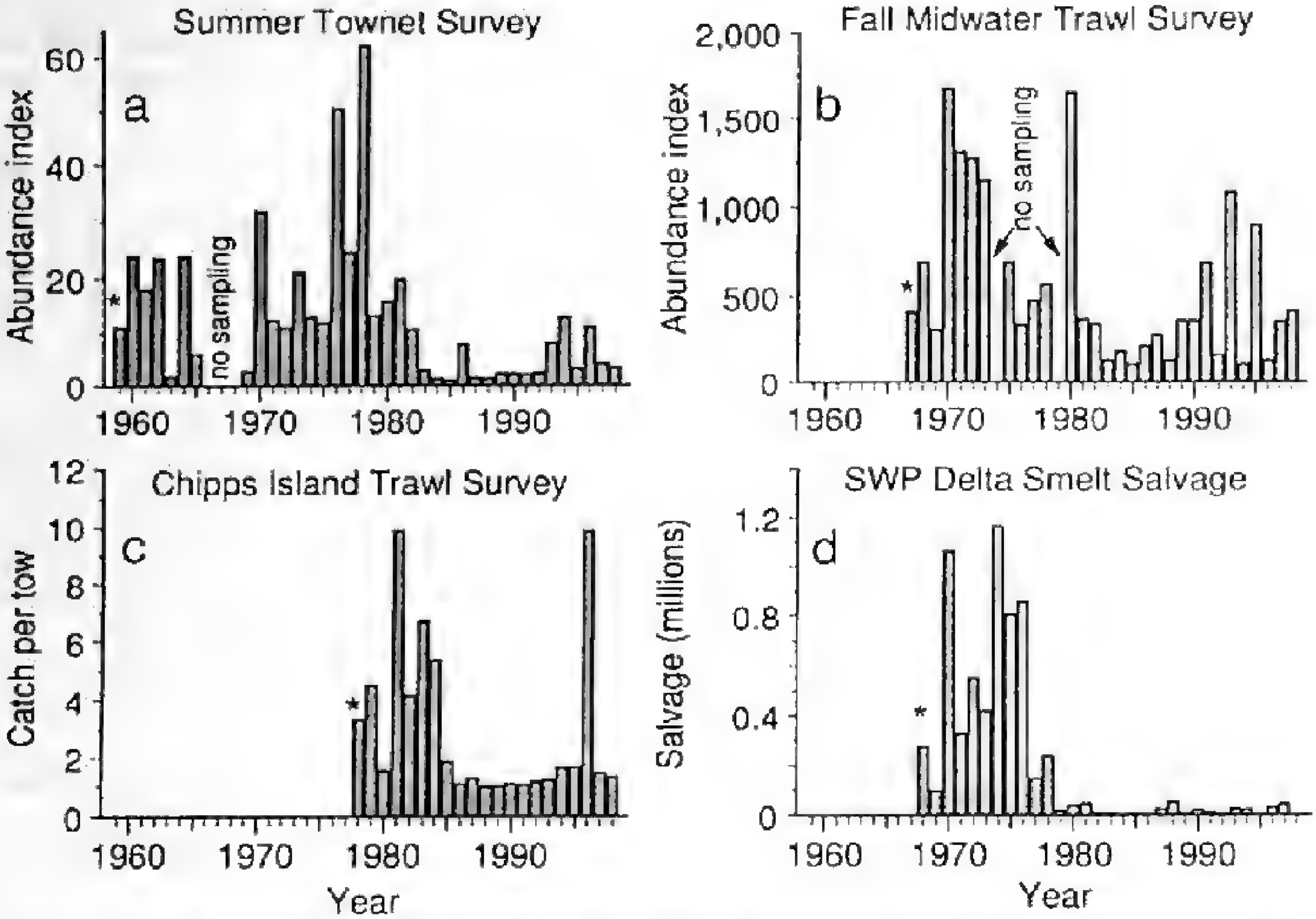

Figure 1. Trends in delta smelt abundance as measured by a) the summer townet survey, b) the fall midwater trawl survey, c) the Chipps Island trawl survey, and d) salvage at the State Water Project (SWP). Asterisks represent the 1st year of sampling. See Sweetnam and Stevens[2] (1993) for a description of each survey.

Distribution of delta smelt in the estuary is strongly related to freshwater outflow (Stevens et al.[1] 1990, Moyle et al. 1992, Sweetnam and Stevens[2] 1993). In low outflow years, delta smelt are concentrated above the confluence of the Sacramento and San Joaquin rivers, whereas in higher outflow years the distribution extends through Suisun Bay (Fig. 3). Because the potential for entrainment, predation, pollutant exposure, and competition with wakasagi is greater in low outflow years (Moyle et al. 1992, Sweetnam and Stevens[2] 1993, Bennett and Moyle 1996), recovery criteria for delta smelt include distribution requirements (USFWS[5] 1995a).

Current research is focused on evaluation of the relative importance of potential mechanisms affecting delta smelt abundance, with the understanding that many of these mechanisms may act in concert or synergistically (Sweetnam and Stevens[2] 1993, Bennett and Moyle 1995).

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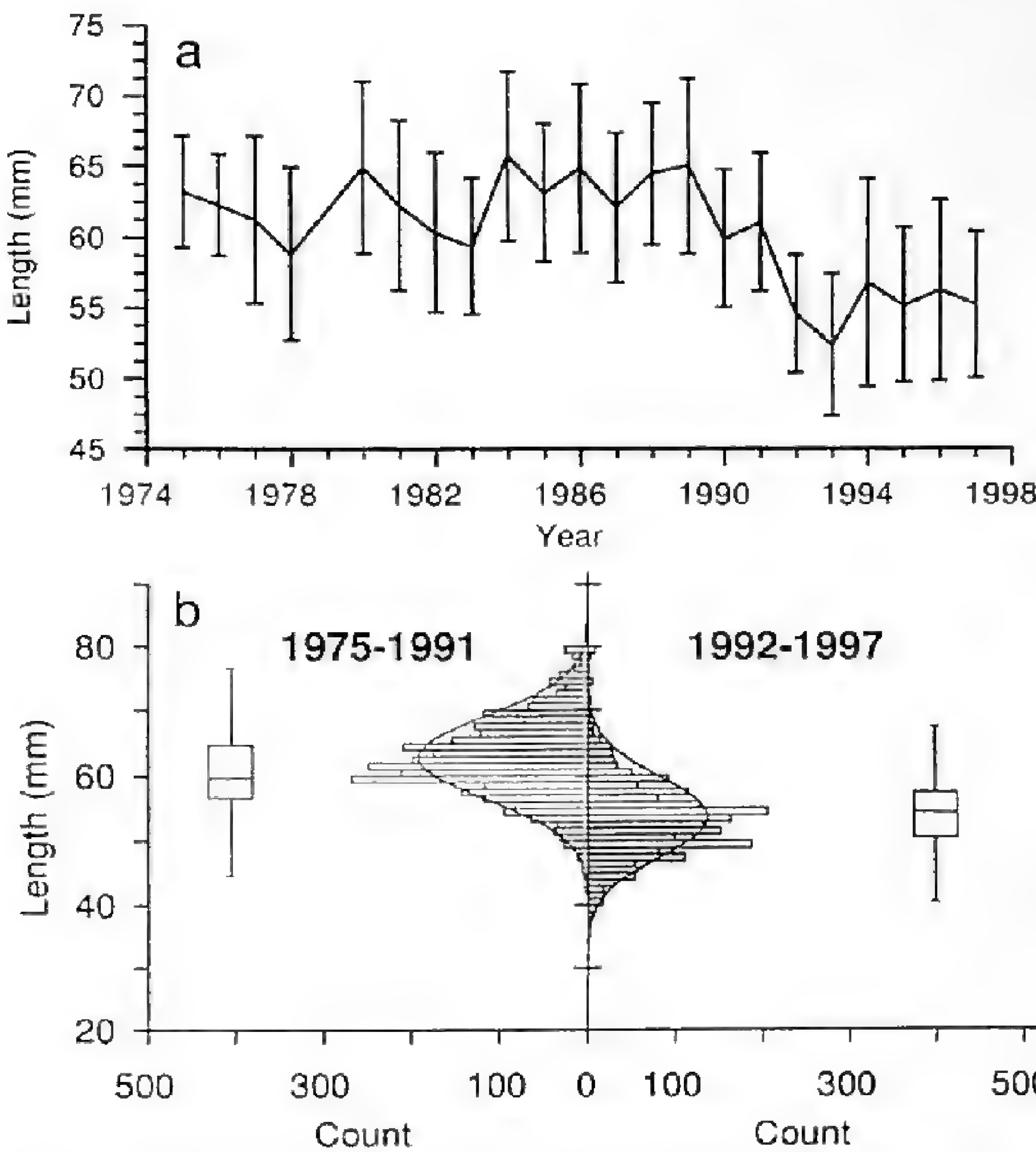

Figure 2. a) Average fork length of delta smelt collected in the fall midwater trawl survey from 1975 to 1997. Bars equal ±1 SD. b) Length-frequency histograms of delta smelt for 2 periods: 1975–1991 and 1992–1997. Bell-shaped curves represent normalized length-frequency distributions and box plots depict median values (center lines), 25th and 75th percentiles (boxes), and 10th and 90th percentiles (whiskers).

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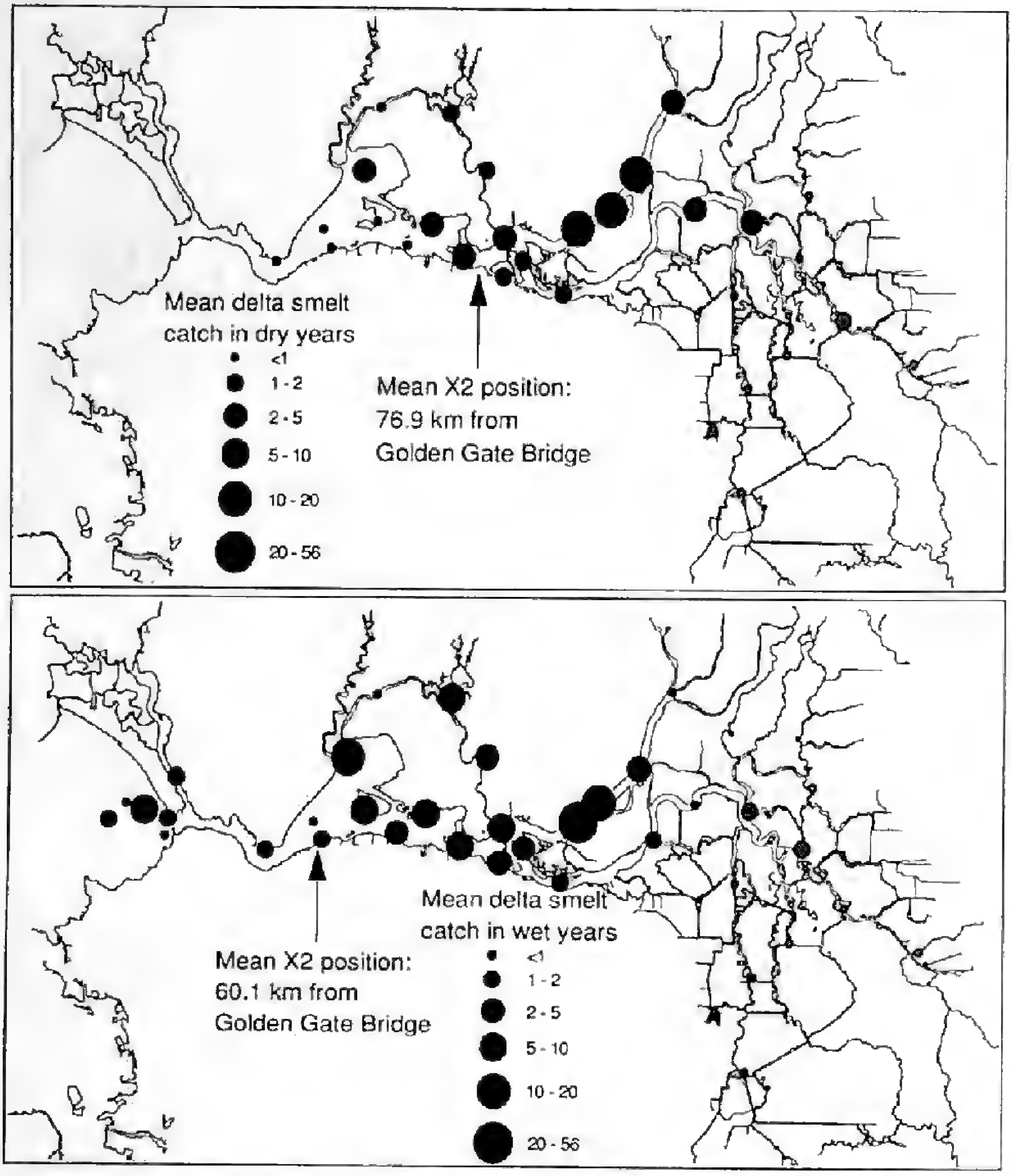

Figure 3. Mean delta smelt catch in the summer townet survey from 1959 to 1995 by water year type: a) low freshwater outflow years, b) high outflow years. Arrows represent mean X2 isohaline (2‰ bottom salinity) position in kilometers from the Golden Gate Bridge (GGB) from February to June. Low outflow years include 1959–62, 64, 66, 68, 72, 76, 77, 79, 81, 85, 87–92, and 94.

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STATUS OF SPLITTAIL IN CALIFORNIA

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The splittail, *Pogonichthys macrolepidotus*, is a medium-sized (<400 mm fork length) cyprinid that historically ranged throughout low-gradient reaches of the Sacramento and San Joaquin rivers downstream to the Sacramento-San Joaquin Delta, Suisun Bay and Marsh, Napa and Petaluma rivers, Coyote Creek, and other tributaries to San Francisco Bay (Rutter 1907, Caywood[1] 1974, Leidy 1984). It is distinguished from other cyprinids by a deeply-forked, asymmetrical tail possessing a larger dorsal lobe and by its extensive use of brackish water (2 to $\geq$10‰). Adult splittails forage and spawn on inundated floodplains and year-class strength is positively related to the duration of floodplain inundation during the March-May spawning period (Sommer et al. 1997). Meng and Moyle (1995) concluded that splittail abundance had declined by 62% during the preceding 13 years and that splittail seldom used the rivers upstream of the delta. In 1999, after 4 years of candidate status, the splittail was listed as "threatened" under the Federal Endangered Species Act (USFWS[2] 1999).

Splittail abundance is monitored by 5 trawl surveys, a beach seine survey, and salvage at the State Water Project and Federal Central Valley Project fish facilities in the south delta (Sommer et al. 1997). A subset of these indices is presented here (Fig. 1 and 2). Length-frequencies were used to separate age-0 fish from older age groups. Distribution information is gathered from a variety of monitoring and research projects throughout the system, as well as from directed sampling.

Most age-0 splittail abundance indices rebounded in 1995 and 1998 from low values recorded during the 1987–1992 drought (Fig. 1). The low abundance of age-0 splittail during the drought was likely the direct result of reduced incidence of floodplain inundation. However, the reduction in adult abundance from several successive years of low age-0 abundance did not prevent a strong reproductive response when favorable outflows returned. The 1995 and 1998 indices were at record or near-record levels as the result of high flows and consistent floodplain inundation. In these years, good reproductive success occurred in the San Joaquin, Sacramento, Cosumnes, Napa and Petaluma rivers and the Sutter and Yolo bypasses. The only location where splittail did not rebound is the Suisun Marsh (Fig. 2).

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[1] Caywood, M.L. 1974. Contributions to the life history of the splittail *Pogonichthys macrolepidotus* (Ayers). M.S. Thesis, California State University, Sacramento, California, USA.

[2] USFWS (U.S. Fish and Wildlife Service). 1999. Endangered and threatened wildlife and plants: Determination of threatened status for the Sacramento splittail. Federal Register, February 8, 1999, 64(25):5963-5981.

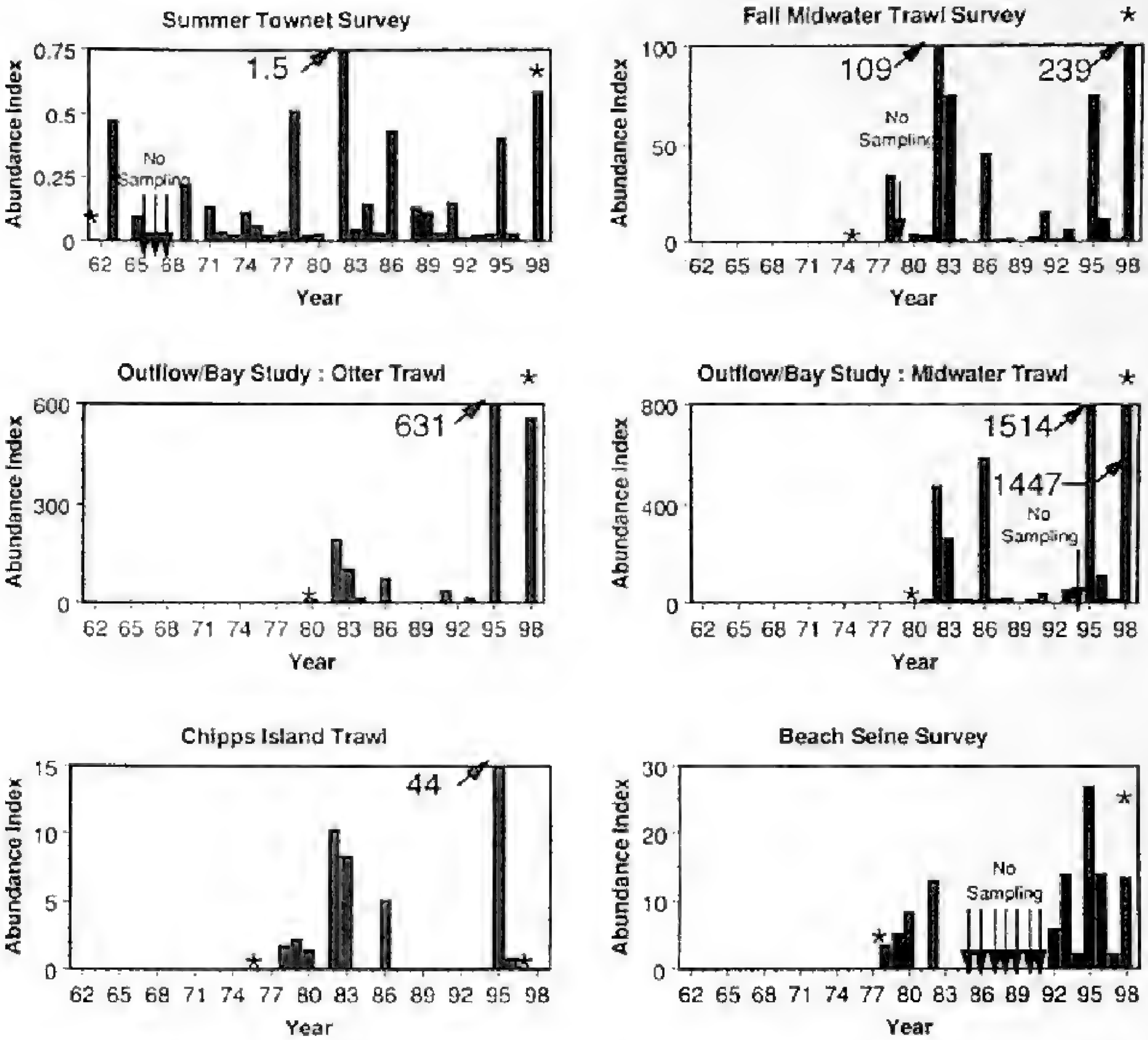

Figure 1. Trends in age-0 splittail abundance in the Sacramento-San Joaquin Estuary and tributary rivers as indexed by 6 surveys. The Outflow/Bay Study samples with otter and midwater trawls at each location, so data are not independent. Asterisks indicate start of survey and most recent calculated index.

Splittail range appears to be expanding because environmental conditions have improved, abundance has increased, and efforts to detect them at the periphery of their known range have increased. Recent collections show that splittail still occur in most drainages within their historic range, with the possible exception of Coyote Creek, but sampling records are insufficient to determine if all habitat below the 1st dam on each drainage is used (Sommer et al. 1997). Sommer et al. report that in 1995 splittail were collected at the Glenn-Colusa Irrigation District diversion near Hamilton City (river km [rkm] 331) on the Sacramento River; at Fremont Ford (State Highway 140 crossing, rkm 201) on the San Joaquin River; and from several other locations, including the Napa and Petaluma rivers.

In 1997, splittail were captured 60 km upstream of previous recent range limits in the Sacramento River. Two adult splittail were collected at the Red Bluff Diversion Dam (rkm 391), 1 in April and 1 in August (C. Martin, U.S. Fish and Wildlife Service [USFWS], Red Bluff, California, personal communication). In October 1998, a dead

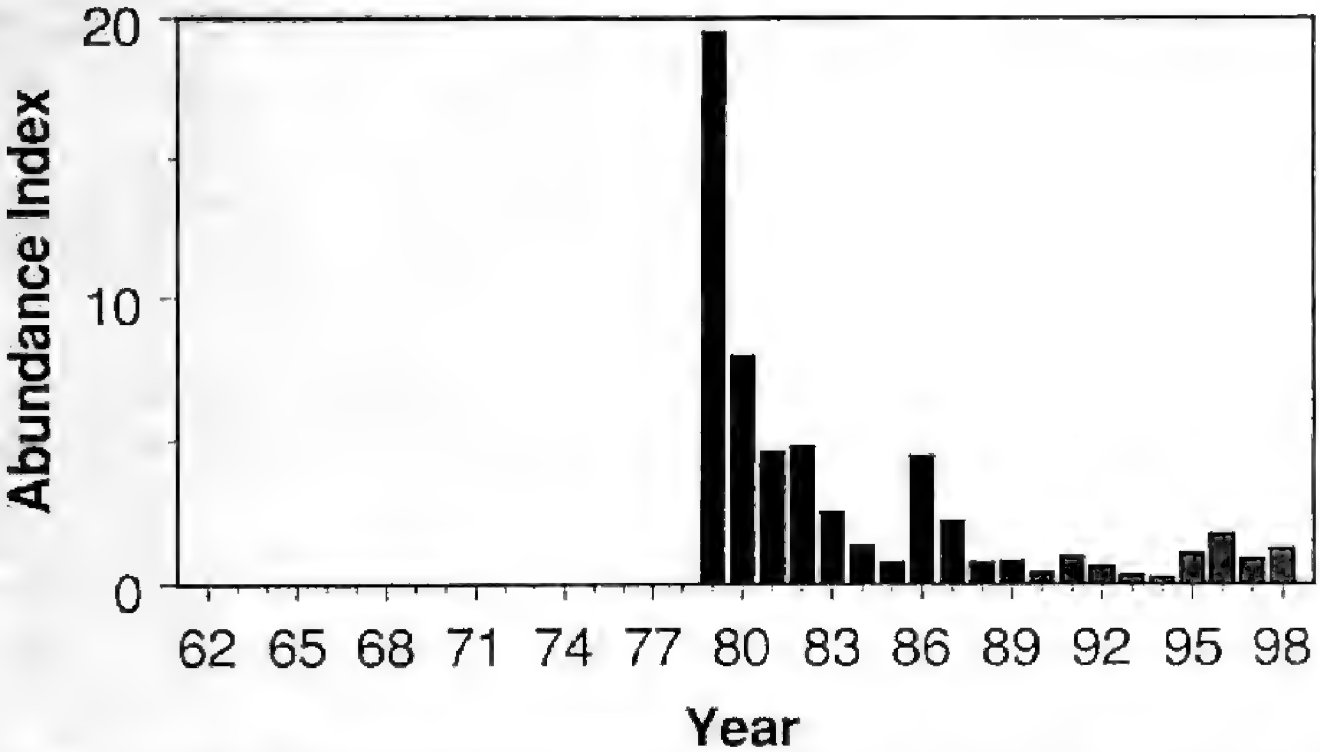

Figure 2. Trends in splittail abundance (all ages combined) in Suisun Marsh based on University of California, Davis otter trawling. Sampling began in 1979.

adult was recovered at Red Bluff (C. Martin, personal communication). These fish represent the most upstream records of collection in the latter half of this century and their timing suggests that some adults spend the summer in the mainstem Sacramento River rather than return to the estuary.

In the San Joaquin River, juvenile splittail were again collected in 1998 at Fremont Ford (California Department of Fish and Game, unpublished data) and a new upstream limit was set in June 1998 when 30 juvenile splittail were collected in Salt Slough (rkm 218.5; rkm 208.5 in the San Joaquin River plus 10 rkm in Salt Slough), San Luis National Wildlife Refuge (J. Henderson, USFWS, Environmental Contaminants Division, Sacramento, California, personal communication). During the same survey, juvenile splittail were also collected in Mud Slough about 8 km upstream from its mouth (rkm 195).

The strong 1995 and 1998 year classes should sustain the splittail population for years to come. Favorable winter and spring flows in future years may lead to further range expansion as these year classes reach maturity and migrate up-river in search of foraging and spawning opportunities.

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STATUS OF STRIPED BASS IN THE SACRAMENTO-SAN JOAQUIN ESTUARY

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California's striped bass population increased dramatically after its introduction into the Sacramento-San Joaquin Estuary in 1879. Sport and commercial fisheries developed before 1900, but commercial fishing was outlawed by the legislature in 1935. The sport fishery, currently with a 45.7-cm minimum total length limit and 2 fish daily bag limit, is now the major fishery in the estuary.

The importance of striped bass as a sport fish and as an indicator of ecosystem health led to many studies of its life history and population dynamics. These resulted in the present extensive knowledge of sexual maturity (Scofield 1931, Chadwick 1965); spawning times, locations, and requirements (Farley 1966, Radtke and Turner 1967, Turner and Farley 1971, Turner 1976); growth rate (Scofield 1931, Collins 1982); food habits (Stevens 1966, Thomas 1967); mortality rates (Albrecht 1964, Chadwick 1968, Miller 1974, Stevens et al. 1985); migrations (Chadwick 1967, Orsi 1971); factors affecting juvenile production and survival (Calhoun 1953, Turner and Chadwick 1972, Stevens 1977a, Stevens 1980, Chadwick et al. 1977, Stevens et al. 1985); tag loss rates (Smith 1978); and the fishery (Chadwick 1969, McKechnie and Miller 1971, White 1986).

Adult striped bass abundance and mortality rates have been monitored since 1969 with mark-recapture techniques (Stevens 1977b). Reward and nonreward disk-dangler tags (Chadwick 1963) are applied to legal-sized striped bass captured during their spring spawning migration in the Sacramento-San Joaquin Delta and the Sacramento River. Recaptures during tagging in subsequent years and during a creel census are used to estimate abundance; tags returned from anglers through the mail and during the creel census are used to estimate mortality rates. From 1969 to 1976, estimates of the legal-sized striped bass population were relatively stable, ranging from 1.5 to 1.9 million fish (Fig. 1a). Since then, estimated abundance has declined, first to 800,000–1.2 million fish in the late 1970s and 1980s, followed by a further decrease to only 579,000 legal-sized fish in 1994.

The adult striped bass population decline primarily reflects reduced recruitment. Estimates of the abundance of 3-year-old fish, which are the youngest and most numerous component of the adult population, have also declined and were at a record low in 1996 (Fig. 1b).

As measured by an annual summer tow net survey, which began in 1959, (Chadwick 1964, Turner and Chadwick 1972), abundance of young-of-the-year (YOY) striped bass when mean fork length of the year class is 38 mm has declined irregularly, but steadily, since the mid-1960s (Fig. 2). Abundance of YOY striped

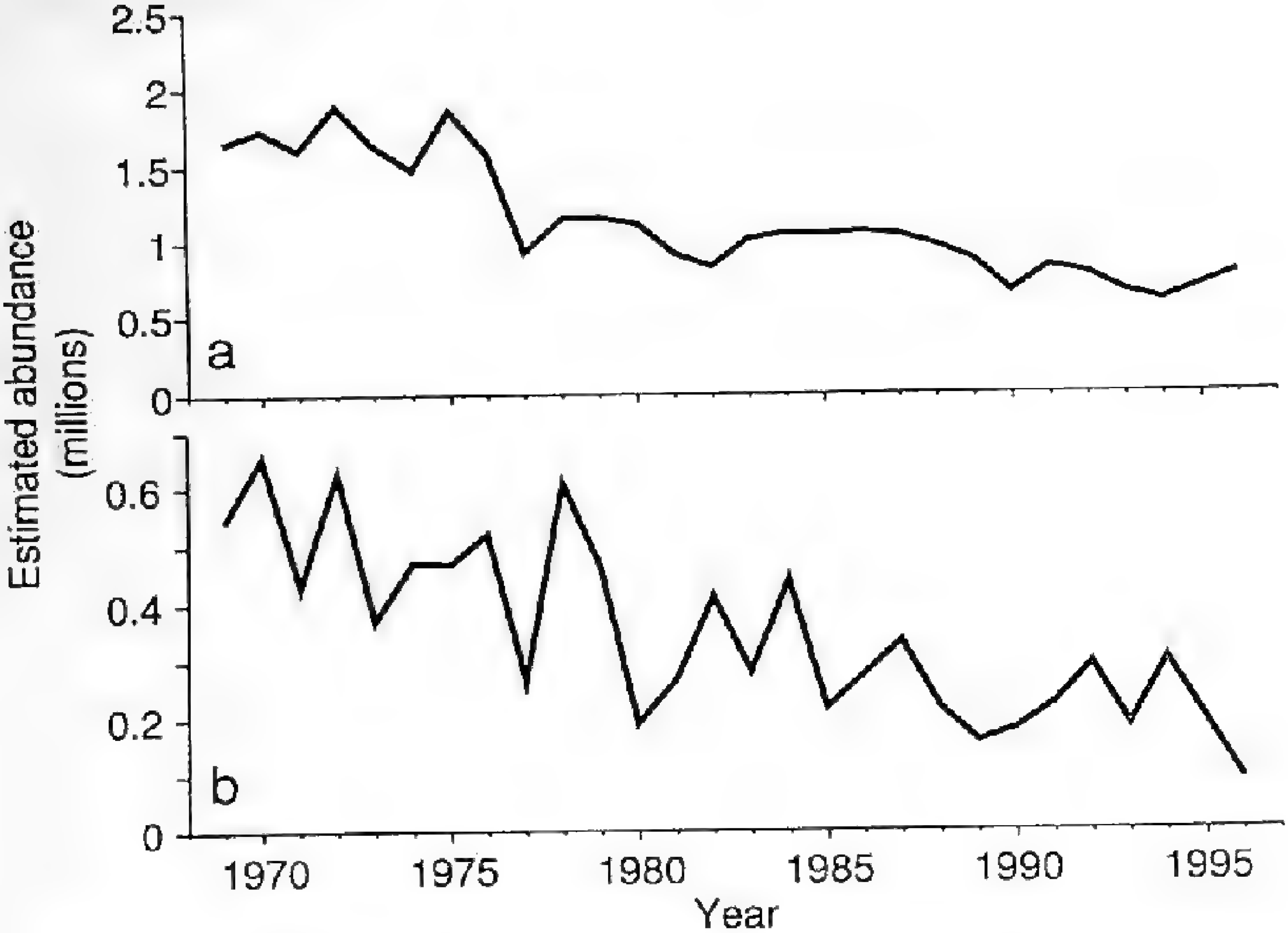

Figure 1. Estimated abundance of a) legal-sized and b) age-3 striped bass in the Sacramento-San Joaquin Estuary, 1969–1996.

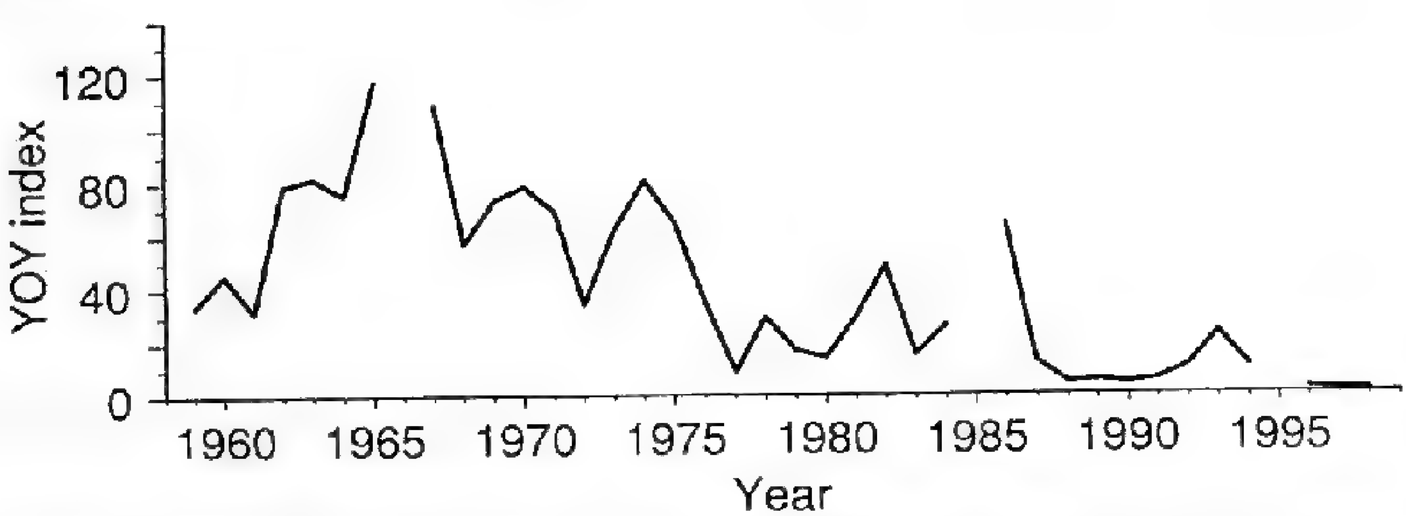

Figure 2. Young-of-the-year striped bass abundance index for the Sacramento-San Joaquin Estuary, estimated in mid-summer when mean fork length of the population is 38 mm, 1959–1998.

bass peaked in 1965, when the index was 117.2. In contrast, YOY striped bass abundance was lowest in 1998, when the index was 1.4. Since 1977, the average YOY striped bass index (16.8) has been only 25% of the average index from 1959 to 1976 (66.6). Evaluations of potential causes of the post-1976 YOY striped bass decline concluded that it probably was caused by some combination of 1) the reduced adult stock producing fewer eggs, 2) reduced food production in the nursery area.

3) increased losses of young fish entrained in water diversions, and 4) toxicity (Stevens et al. 1985).

This decline in production of young striped bass has likely contributed substantially to the decreased recruitment of 3-year-old fish (Stevens 1977a, Stevens et al. 1985). Recent meager year classes provide no expectation for imminent recovery of the depressed adult stock.

In addition to the effect on recruitment of decreased young striped bass production, estimated mortality rates of adults also have changed. Estimated total annual mortality rate has shown a significantly increasing trend since 1969 ($F = 7.35$; $df = 1, 24$; $P < 0.05$) and reached its highest level (0.67) in 1993 (Fig. 3). This change in total mortality is the result of a significant increase in estimated "natural" (due to factors other than legal fishing) mortality rate ($F = 14.1$; $df = 1, 24$; $P < 0.01$), whereas estimated harvest rate exhibited a significant downward trend ($F = 9.89$; $df = 1, 25$; $P < 0.01$) (Fig. 3). The cause(s) of the increase in estimated natural mortality is unknown.

As a result of the initial decline in estimated legal-sized striped bass abundance in the late 1970s, and also in response to public pressure for supplementation stocking, the California Department of Fish and Game began a hatchery program starting with the 1980 year class, stocked as yearlings in 1981. The number of fish stocked increased from about 63,000 for the 1980 year class to almost 3.4 million for the 1990 year class (Fig. 4a).

The hatchery program changed substantially in 1992 as a result of concern over potential predation by striped bass on threatened and endangered species, such as Sacramento River winter-run chinook salmon, *Oncorhynchus tshawytscha*, and delta smelt, *Hypomesus transpacificus*, and all stocking of hatchery-reared striped bass was suspended (Age-1 fish from the 1991 year class were not stocked in the estuary). Instead, 22,000–284,000 fish obtained from fish screens in the southern Sacramento-San Joaquin Delta and reared in floating pens have been stocked annually,

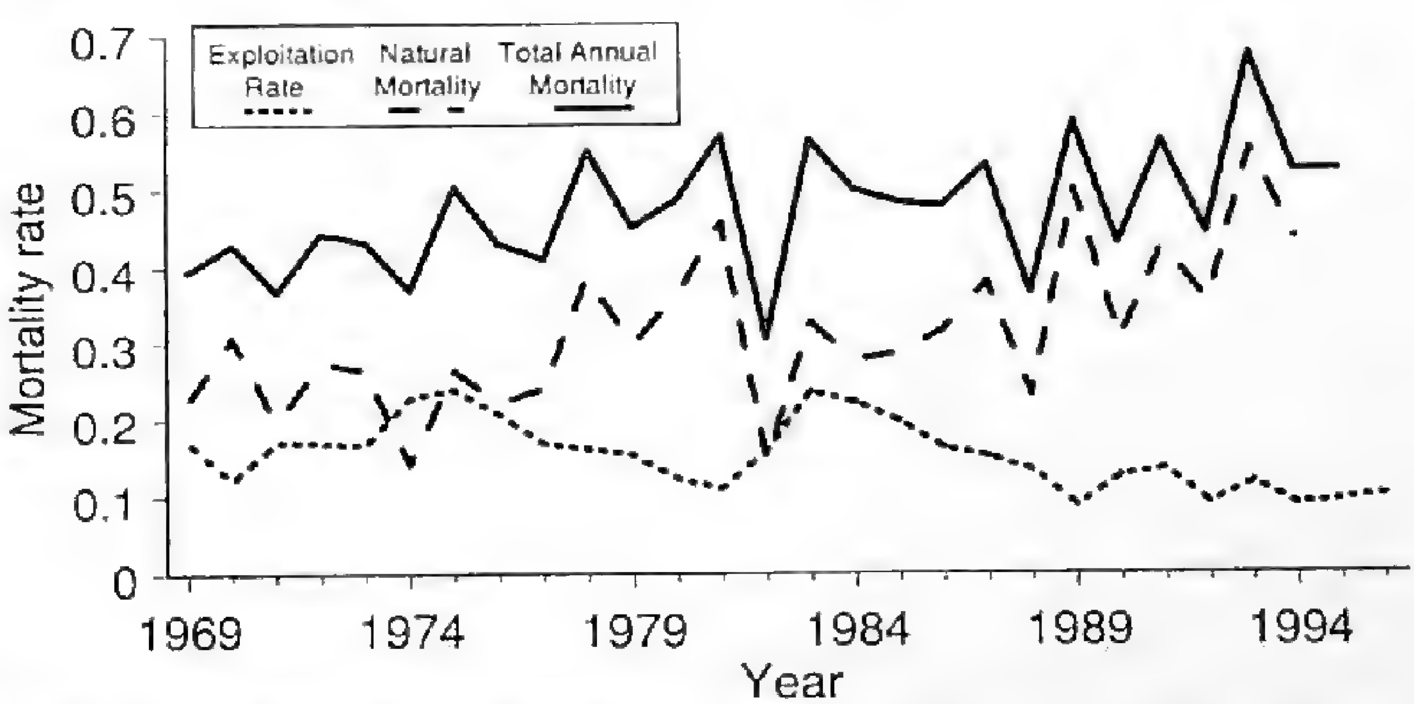

Figure 3. Estimated mortality rates of legal-sized striped bass in the Sacramento-San Joaquin Estuary, 1969-1996.

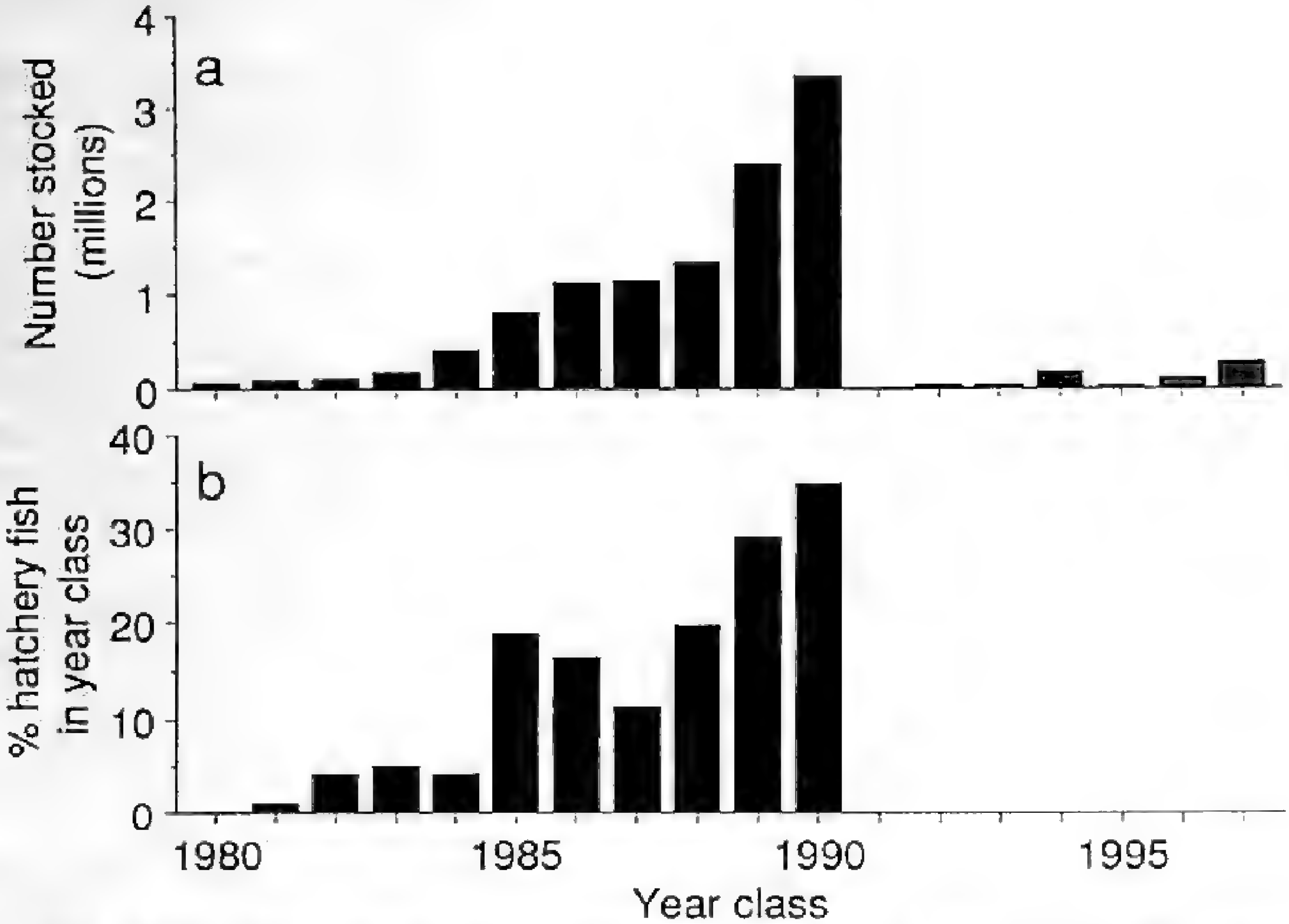

Figure 4. a) Number of hatchery-reared striped bass stocked in the Sacramento-San Joaquin Estuary, 1980–1997 year classes. b) Percent contribution of hatchery-reared fish to each striped bass year class in the Sacramento-San Joaquin Estuary from the 1981 to the 1990 year class. No hatchery fish were marked in 1980 and data have not been summarized for net-pen-reared year classes from 1992 to 1997.

beginning with the 1992 year class released as yearlings in 1993 (Fig. 4a). In most years, a fraction of the stocked fish have been externally marked or coded-wire tagged to allow estimation of their contribution to the population.

Hatchery fish have contributed measurably to the population of each year class in the estuary, especially at the higher stocking levels. Estimated percentage of hatchery-reared striped bass in each year class increased from about 1% for the 1981 year class to almost 35% for the 1990 year class (Fig. 4b) (Harris and Kohlhorst[1], in review). The contribution of hatchery-reared striped bass to each year class is linearly related to stocking rate ($r^2 = 0.88$, $P < 0.001$).

Greater stocking of age-1 and age-2 striped bass (up to 1.275 million age-1 equivalents) reared in hatcheries and pens is planned to begin in summer 2000. This stocking is the focus of the Striped Bass Management Conservation Plan being prepared according to federal Endangered Species Act requirements. It is designed

[1] Harris, M.D. and D.W. Kohlhorst. In review. Survival and contribution of hatchery-reared striped bass stocked in the Sacramento-San Joaquin Estuary. North American Journal of Fisheries Management.

to maintain the striped bass population and sport fishery at the present (defined as 1994) level and to be consistent with recovery of listed species (CDFG 1998[2], 1999[3]).

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STATUS OF WHITE STURGEON IN THE SACRAMENTO-SAN JOAQUIN ESTUARY

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Two species of sturgeon, white, *Acipenser transmontanus*, and green, *A. medirostris*, inhabit the Sacramento-San Joaquin Estuary; white sturgeon is the most abundant. In the late 1800s, the commercial fishery for sturgeon in the Sacramento-San Joaquin Estuary depressed the populations to the point where all fishing was prohibited in 1917. In 1954, the sturgeon fishery was re-opened for sport fishing with a 102 cm total length (TL) minimum size and a limit of 1 fish per day and in possession.

Coincident with the reopening of the sport fishery, the California Department of Fish and Game (CDFG) and others began studies of white sturgeon life history and population dynamics. These studies described white sturgeon spawning time and location (Stevens and Miller 1970, Kohlhorst 1976, Schaffter 1997), size at maturity and spawning periodicity (Chapman et al. 1996), food habits (Schreiber 1962, McKechnie and Fenner 1971), mortality rates (Chadwick 1959, Miller 1972b, Kohlhorst 1979, Kohlhorst et al. 1991), migrations (Miller 1972a), growth (Kohlhorst et al. 1980), abundance (Pycha 1956, Miller 1972b, Kohlhorst 1980, Kohlhorst et al. 1991), and factors affecting abundance (Kohlhorst et al. 1991).

The CDFG intermittently monitors the status of white sturgeon primarily with a mark-recapture program to estimate abundance and mortality rates. Legal-sized (presently 117–183 cm TL) fish are captured in trammel nets in San Pablo Bay in fall and tagged with disk-dangler reward tags (Chadwick 1963, Kohlhorst 1979). Abundance is estimated with multiple-census or, if recaptures during tagging in subsequent years are numerous enough, Petersen techniques (Ricker 1975). Annual exploitation rate is estimated from angler returns of tags by dividing the number of tags returned within 1 year by the number of tags released. Annual survival rate is estimated using Ricker's (1975) equation 5.1 when tagging occurs in 2 consecutive years; otherwise, lengths are converted to ages using an age-length key developed in 1973–1976 (Kohlhorst et al. 1980) and survival is estimated from the slope of the right-hand limb of the resultant catch curve (Ricker 1975). To assure nearly complete reporting of tagged fish, rewards have varied from $5 to $100 over the years. In response to potential overexploitation in the mid-1980s, the present "slot" size limit was instituted in 1990 by increasing the minimum size from 102 to 117 cm in 5-cm annual increments and setting a 183-cm maximum length. Catch of white sturgeon outside the "slot" is still recorded during tagging and estimated abundance and exploitation rate are adjusted to make them comparable to the pre-1990 estimates.

Adult (≥102 cm TL) white sturgeon abundance varied greatly between 1967 and 1998 (Fig. 1). The abundance estimate reached its highest level (142,000) in 1997. This abundance pattern is largely the result of irregular recruitment to the adult population by highly variable year classes. Strong year classes are produced in years with high spring freshwater outflows from the Sacramento-San Joaquin Delta (Kohlhorst et al. 1991), so much of the present high white sturgeon abundance is attributable to the very wet 1982–1983 period.

Unfortunately, the severe drought that gripped California from 1987 to 1992 will soon begin to affect the adult white sturgeon population because reproductive success was low in most of those years. This incipient meager recruitment already is evident in length frequencies from catches in trammel nets during tagging in the 1990s (Fig. 2). The strong year classes from the early 1980s were recruited starting in about 1994 and, by 1997 and 1998, few fish smaller than the minimum size limit of 117 cm were caught. Thus, the population should decline substantially as recruitment almost ceases and growth and mortality reduce the abundance of fish now in the fishable population. However, another cycle of strong recruitment can be expected when fish from a series of wet years starting in 1993 begin to enter the fishery late in the next decade.

Estimates of exploitation and survival rates give a mixed picture of the status of white sturgeon mortality. Annual exploitation rate estimates indicate that the angling regulation changes begun in 1990 have had the desired effect: exploitation rates have been reduced by at least half from the levels of the mid- to late 1980s (Fig. 3) and are now <0.05. Conversely, annual survival has exhibited a significant ($F = 7.02$; df = 1, 10; $P < 0.05$), and unexplained, declining trend, mostly since 1987 (Fig. 4). Potential causes of the decline in estimated survival rate include alterations in the food supply due to introductions of exotic benthic invertebrates, pollutants, illegal fishing and associated lack of reporting of tagged fish catches, and the unreliability of catch curve survival estimates when recruitment varies.

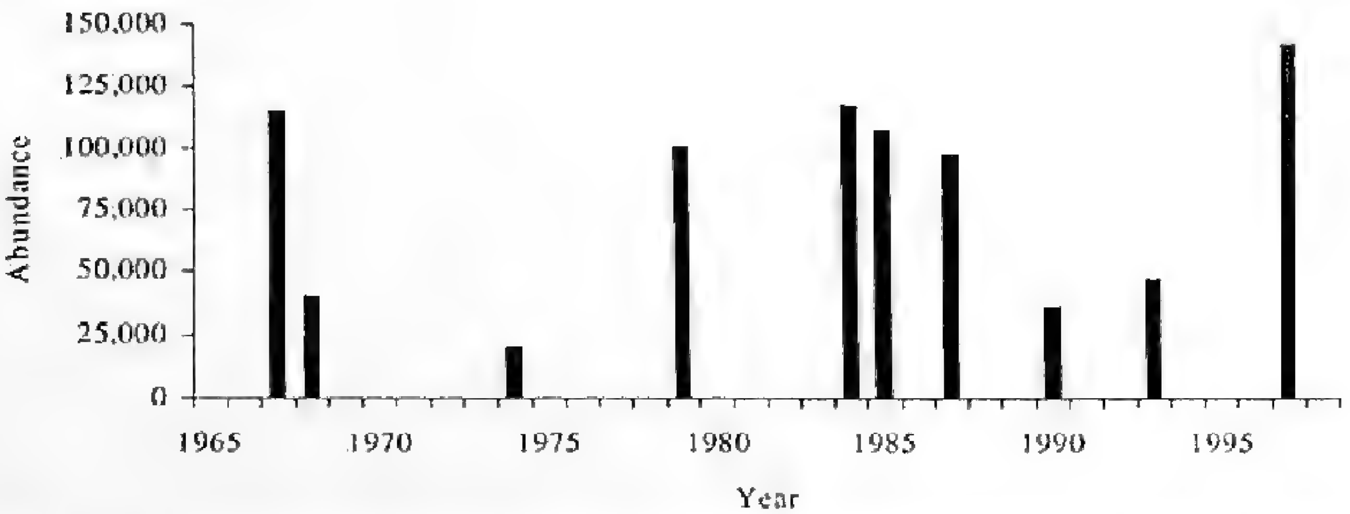

Figure 1. Estimated white sturgeon abundance in the Sacramento-San Joaquin Estuary, 1967–1997.

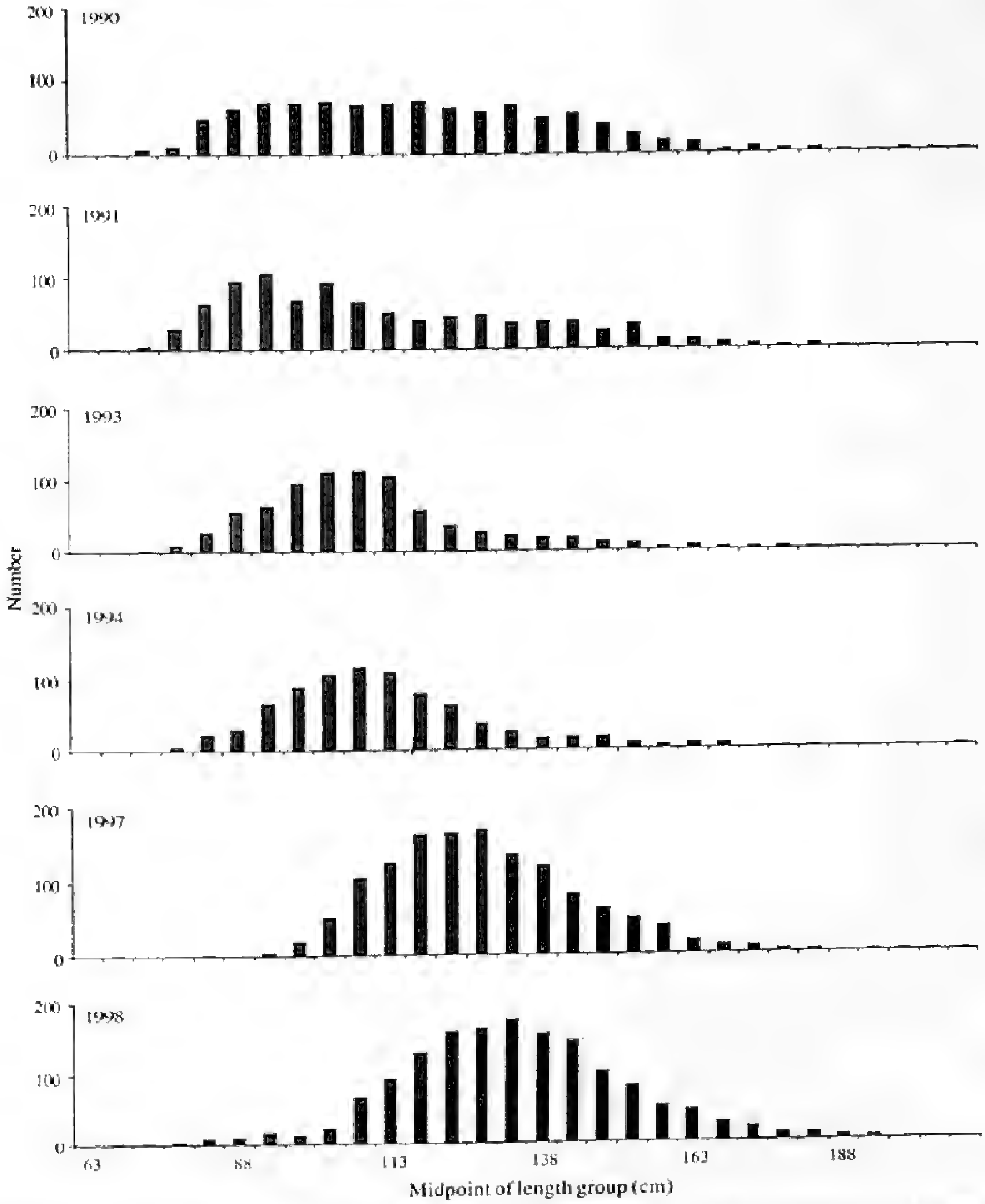

Figure 2. Total length frequencies of white sturgeon captured in trammel nets in fall in San Pablo Bay during the 1990s.

The present low exploitation rates, past rapid recoveries from population lows in the mid-1970s and early 1990s, and current protection of the most fecund females by the 183-cm maximum size limit suggest that no further angling restrictions are needed. Continued monitoring of the abundance and mortality rates, especially in light of the potential reduction in survival rates over the last 30 years and the long time from year class formation to recruitment, are necessary to assure a sustainable population.

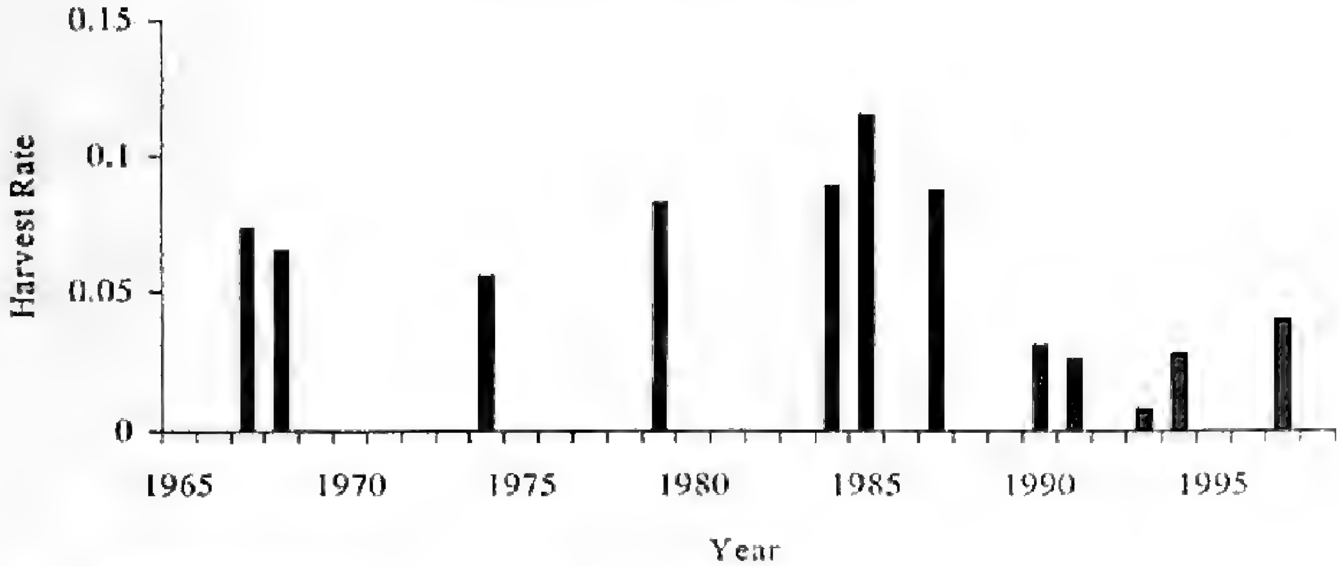

Figure 3. Estimated exploitation rate of white sturgeon in the Sacramento-San Joaquin Estuary, 1967–1997.

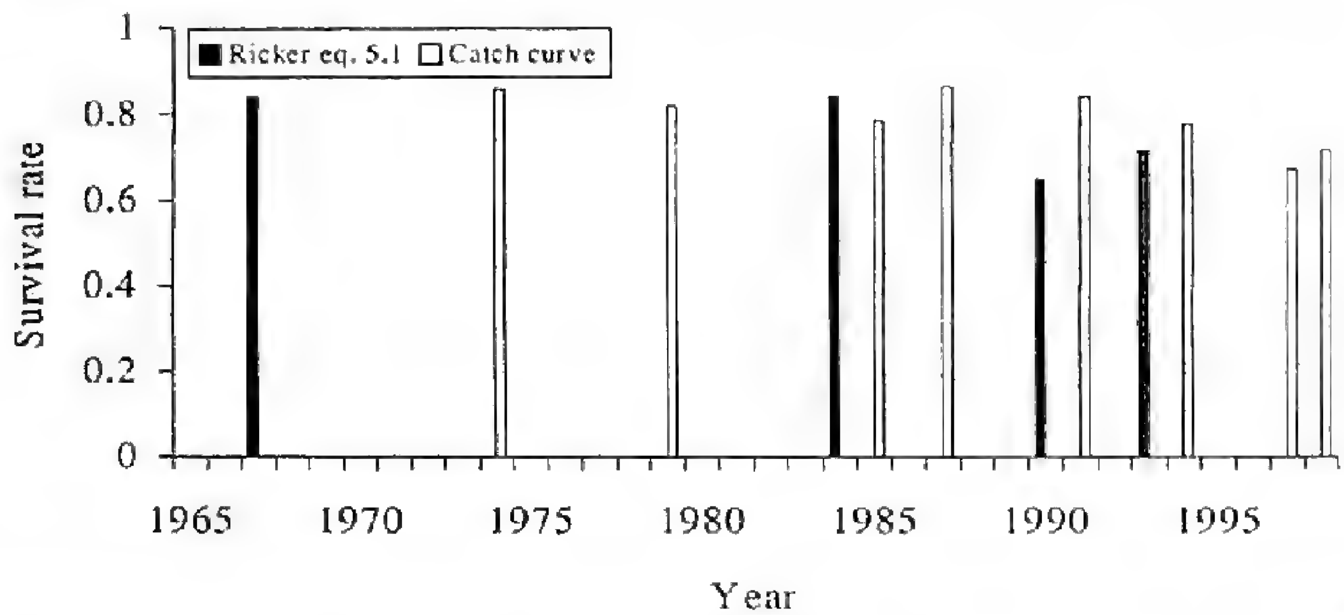

Figure 4. Survival rates of white sturgeon in the Sacramento-San Joaquin Estuary, 1967–1998 estimated using Ricker (1975) equation 5.1 or catch curves from tagging catches.

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BOOK REVIEW

THE MARIN COUNTY BREEDING BIRD ATLAS by W. David Shuford. 1993. Bushtit Books, P.O. Box 233, Bolinas, California 94924, USA. xv + 479 pages. $24.95.

ATLAS OF THE BREEDING BIRDS OF MONTEREY COUNTY, CALIFORNIA. Edited by Don Roberson and Chris Tenney. Monterey Peninsula Audubon Society, P.O. Box 5656, Carmel, California 93953, USA. viii + 438 pages. $19.95.

Traditionally, books on the distribution of organisms have summarized all data available for a region, placing them in an environmental and historical context. California ornithology has a rich heritage of such studies, due largely to the efforts of Joseph Grinnell and those inspired by him. Even more than 50 years after their publication, the maps in Grinnell and Miller's *Distribution of the Birds of California* represent the best portrayal of the breeding ranges of many California birds. Today, however, changes in land use are rapidly altering bird distributions and land-use planning now requires distributional data on a far finer scale than available in the past. Development of breeding-bird atlases helps meet this need.

Breeding-bird atlases have been published for 4 California counties (Marin, Monterey, Sonoma, and Orange) and similar efforts are underway in several others. This review addresses the atlases for Marin and Monterey counties, which I believe are the best so far.

These atlases inventory breeding birds on a grid system based on field surveys within a specific time period. The grid system serves as a framework free of preconceptions of habitat suitability and imposes a degree of uniformity. Ideally, all grid cells should receive equal survey effort, but that is never possible. To their credit, both of these atlases achieved some coverage in every cell. Thus, these books convey a good idea of where species are absent as well as where they are present.

Likewise, specificity in time is one of the advances of these atlases. The Marin atlas is based on field work from 1976 to 1982; that for Monterey, from 1988 to 1992. Therefore, they can serve as controls for testing hypotheses concerning temporal changes in bird distributions.

Adequate coverage for even a small county like Marin requires great effort and must necessarily rely on volunteers. Luckily, Marin County is blessed with a large number of talented and motivated amateurs, many of whose bird-identification skills exceed those of the average professional biologist. About 170 are listed in the acknowledgments. In Monterey County, by contrast, 1/6 as many participants attempted to cover an area 6 times as large. The ratio of observers to area in Monterey County is probably close to the lowest that can yield useful results in a volunteer-based project.

The basic data reported in these atlases are presence or absence by grid cell, breeding status (based on defined behavioral criteria), and relative (and rough) indices

of abundance. More precise estimates of population densities and abundance are not practical on the scale of an atlas whose goal is to determine distributions over a broad area.

The Marin and Monterey atlases, despite the similarities imposed by the same organizing principle, differ in several respects. The greater density of observers in Marin County permitted use of a grid of cells 2.25 x 2.75 km, similar in size to those used in European bird atlases. The Monterey project used a 5-km grid, the size used in most American bird atlases. Thus, a comparison of the 2 atlases requires that 4 Marin blocks be combined to yield approximately 1 Monterey block.

Each atlas consists of an extensive explanatory introduction followed by detailed species accounts, accompanied by maps. A major objective of the Marin atlas is to discuss each species' broader biology, not restricted to Marin County. The "ecological requirements" sections in each species account are commonly 5–10 times longer than the "Marin breeding distribution" sections and provide outstanding summaries of each species' natural history, based largely on a thorough study of the literature. The maps speak largely for themselves, with the text serving mainly to provide context on habitats and historical changes. The Monterey atlas is more balanced, with discussion of results of field work roughly equaling summaries of the literature. Future atlases should be restricted to presentation and interpretation of local distributions to avoid duplication of discussions of biology.

Improvements in these atlases would make them easier to use. For example, the grid system and index designations should be on every map. Then it would be easier to determine which species have been recorded in a block. Species maps like those in the Marin atlas, which have a background of the entire grid system plus roads and water features, help locate specific blocks, especially if the index system is added. Species maps could be enhanced by the addition of vegetation types, topography, and land use or ownership. Including 1 or 2 additional relevant variables on maps should be possible without cluttering them.

Given the potential for such atlases to advance our understanding of bird distribution, the challenge now is to coordinate California's volunteer efforts and extend them into areas that cannot support an entirely volunteer-based project, using both public and private resources. An additional need is to broaden these atlases to include wintering birds, as has been done in France and Britain.

Although California's biodiversity is among the best known in the world, the Marin and Monterey breeding-bird atlases represent a promising new framework for understanding and appreciating a local avifauna. This review has been barely able to touch on the wealth of information in these books.

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